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NATIONAL FOREST SYSTEM WORKING CIRCLES: A question of size and ownership composition

Robert J. Hrubes

Changes in the size of working circles, or planning units, have been a traditional element in the management of the National Forests. Thirty years ago, the average working circle was the size of a National Forest ranger district. The present size of a working circle often coincides with that of a National Forest (Teeguarden 1974). This change over time has occurred in the absence of a stated rationale concerning the size of the working circle. Rather, it has taken place in response to changes in the technological and economic environment of timber production. As timber processing facilities have shifted and consolidated, the supply areas for stumpage flowing into mills have expanded. Similarly, technological improvements reducing transportation and processing costs have provided most wood processors a geographically wider range of suppliers.

As working circles beyond the size of a single National Forest have recently been considered, increasing attention is being given to the possibility of using the size of the working circles as a policy instrument. For the size of working circles to be considered a policy variable, analysis is required of the probable economic and political consequences. One consequence would be the effect on both the timber supply and the stability of local economies.

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Allowable-cut (potential yield) levels on National Forest land are determined for planning units called working circles. The size of working circles has been increased over the past 30 years to the present scale which is often coincident with National Forest boundaries. Larger working circles have recently been considered because of the anticipated impacts on timber supply. A larger total potential yield could result from larger working circles. Alternatives for expansion of working circles must be assessed in light of present Forest Service timber management policy and the impacts of timber supply. These alternates include (a) combination of National Forests, (b) multi-ownership units, and (c) regional planning units. Present policy serves to limit the feasibility of larger working circles. Feasible alternatives would require a change in basic management policy.

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Retrieval Terms: allowable-cut effect; decisionmaking; National Forest System; timber management policy; working circles.

Greater timber supplies may result from larger working circles because of the nature of the volume regulation constraints applied to a planning unit. As noted by Bell,[1] Forest Service planners have observed that a forest managed under some form of volume control with flow constraints may show a synergistic increase in the potential yield (allowable cut) when the landbases for the calculation (i.e., working circles) are combined. This phenomenon has been labeled by Schweitzer, Sassaman, and Schallau (1972) as the allowable-cut effect (ACE) and by Teeguarden (1973) as the timber inventory effect (TIE). Regardless of the name, one effect from enlarged working circles could be an increase in the allowable cut.

Larger working circles may also have repercussions on the economic stability of local communities. The economic viability of local communities has been a traditional concern and goal of Forest Service timber-management policies (U.S. Forest Service 1970). But the traditional orientation toward community-level economic stability has been questioned in recent years. Larger working circles may be consistent with recent interpretations of economic stability.

TIMBER SUPPLY

Many small timber processors in the Western United States have exhausted their own growing stocks and are becoming increasingly dependent upon Forest Service timber for their economic survival. Because of its responsibility for the welfare of local communities, and the pressure exerted by some industry factions, the Forest Service must seriously consider higher levels of cut from western National Forests as a policy alternative. Larger working circles would allow the Forest Service to harvest an increased flow of stumpage from the National Forests without deviating from the nondeclining even-flow policy. Thus, increasing the size of working circles could be considered as one administratively expedient means to increase the flow of stumpage from western National Forests. For an allowable-cut effect to be realized, however, several assumptions must be satisfied:

1. The cut is determined with volume regulation under sustained yield.
2. Allowable-cut determination is, at least in part, a function of the growth rates of the stands in the working circle.
3. Flow constraints are imposed on the allowable-cut determination. The more binding the constraints, the greater the allowable-cut effect, other factors being equal, e.g., even-flow will result in the largest ACE.
4. An existing reserve of mature timber is available within the augmented working circle.

All of these assumptions are satisfied on the western National Forests. This is no coincidence since ACE evolved as an investment guide for National Forest timber management in the Western United States.

The key to ACE lies in the productivity of the stands in the component land units, as reflected through the stand inventories (age-acre arrays). Roughly speaking, the greater the disparity in age-class distribution between the stands, the greater the potential allowable-cut effect. Under any type of volume regulation, the allowable cut may be increased by combining young, fast-growing stands with old-growth, slow-growing stands. The old-growth and young-growth stands complement each other when combined. As the age-class distribution is always improved through combining land units, if only minimally, ACE is theoretically always positive. But in similar stands, the allowable-cut effect of combining them may be negligible.

This so-called allowable-cut effect is not a biological phenomenon. Rather, it is due to the constrained nature of the harvest scheduling problem under even-flow, and to a lesser degree under less stringent flow constraints.

ECONOMIC STABILITY

Concern for the economic stability of timber-dependent communities first evolved from the era of "cut out and get out" harvesting and was formalized in spirit through the Sustained Yield Act of 1944. To date, the orientation toward stabilizing individual communities built around a central conversion/processing facility has not changed. But the socio-economic structure of most timber-based communities has significantly changed. The danger of communities stranded in the wake of transient timber industry no longer exists as it did in the early 1900's.

Some economists have argued that it is no longer appropriate to view economic stability in terms of individual communities (Schallau 1974). Regional economic stability may be better served through a reallocation of resources that could entail the shifting of entire communities. This approach would be a significant departure from the present Forest Service policy.

[1] Bell, Enoch. 1975. *Timber harvesting policy issue report, effect of size of planning unit on allowable cut.* (Unpublished report, on file at Pacific Northwest Experiment Station, U.S. Forest Service, Portland, Oreg.)

In addition, the use of a sustained or even-flow of stumpage to insure economic stability has been questioned. Kromm (1972) points out that an even-flow of raw material into processing facilities cannot insure economic stability (i.e., community employment) because of such factors as increased mechanization and worker productivity. Empirical work by Schallau, Maki, and Beuter (1969) supports this contention. They project that some timber-dependent communities in the Douglas-fir region will experience depopulation even with an increased harvest rate from National Forests.

Larger working circles might be more rational under the alternative orientation to economic stability. The stability of a subregion, rather than of an individual community, could be promoted more efficiently if the entire land base were managed in a single working circle. Teeguarden (1974) suggests that larger working circles would also reduce the importance of maintaining an even flow of timber because of the increased diversity in the economic system of a larger geographic area.

In spite of the arguments for an alternative interpretation of economic stability, possible frameworks for expanding working circles must be assessed in terms of their impacts on stability, as currently interpreted by the Forest Service. One argument for a continued orientation toward individual community stability is the potentially high political costs of abandoning that policy. That a phasing out of a community is economically efficient from a regional point of view would not appease the people adversely affected.

ALTERNATIVES

The even-flow, nondeclining yield policy currently in effect on the National Forests serves to limit the number of feasible alternatives for expanding the size of the working circle. Even-flow nondeclining yield, as currently interpreted, requires that the allowable-cut levels not fall over time. The impact of this constraint depends on the age-class characteristics of the stands. Because of the abundance of old growth in the western National Forests, the even-flow policy acts as an upper constraint on the present allowable-cut level. To insure that future allowable-cut levels will not decrease when the old-growth is exhausted, the cut level for the present and next several decades must be suppressed below the silvicultural and economic optimal level. This projected drop in allowable harvests is known as the *allowable-cut falldown.*

Given this policy, a primary concern of National Forest planners is to insure that a future falldown in cut levels does not occur. The necessity of insuring against a falldown is the key factor in limiting the number of feasible alternatives for increasing the size of the working circle.

Logically, an alternative is acceptable in terms of the even-flow premise if at least one of these two conditions is met: (a) The Forest Service has direct control over the inter-temporal scheduling of the harvest; or (b) in the absence of direct Forest Service control, the harvests from the working circle timber base can be expected to flow at a nonerratic, if not even, rate.

Alternative 1
Combinations of National Forests

Under the requirements generated by the even-flow policy, an obvious alternative for the expansion of working circles is to combine National Forest lands. Complete control over the scheduling process would be maintained and an even-flow harvest could be assured. Since no other land ownerships would be involved, the administrative costs of enlarging the working circle would be lower than those for expansion involving other ownerships.

Preliminary studies have been made in which trial allowable-cut levels were calculated for units comprised of several National Forests. In these tests, Timber RAM—a resource allocation model—was used to determine the allowable cut (Navon 1971). Varied allowable-cut effects have been observed. Price[2] combined the Klamath, Six Rivers, Umpqua, and Rogue River National Forests. He found that in the first decade, the allowable-cut effect exceeded 20 percent, but the effect was much smaller in subsequent decades. Bell[1] reported that an allowable-cut effect of 1.5 percent in the first decade was realized when the east- and west-side working circles of the Mt. Hood National Forest were combined. Navon[3] found a 7.5 percent allowable-cut effect when he combined seven National Forests in northern California. Simonson[4] combined the Malheur, Umatilla, and Wallowa-Whitman National Forests in Oregon

[2] Price, Frank. 1973. *Forest regulation study.* (Unpublished report, on file at Pacific Northwest Region, U.S. Forest Service, Portland, Oreg.)

[3] Navon, Daniel. 1970. (Unpublished data, on file at Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Berkeley, Calif.)

[4] Simonson, J. 1974. (Unpublished data, on file at Pacific Northwest Region, U. S. Forest Service, Portland, Oreg.)

and estimated that the allowable cut for the aggregate unit was only 1 percent over the sum of the three individual allowable-cut levels for the first decade.

The generally insignificant allowable-cut effects may be explained by the nature of the comparative stand structures of the National Forests studied. With some exceptions, National Forests in the three Pacific Coast States show a predominance of old growth with insufficient level of young growth. The growth potential, as reflected through the age-acre arrays, of the National Forests is roughly equivalent. The magnitude of the allowable-cut effect is a function of the degree of similarity in stand composition of the component land units. Component land units with similar age-acre arrays, such as the western National Forests, tend to yield insignificant allowable-cut effects when combined.

Alternative 1 is also inadequate for meeting the criterion of community stability. Concern to promote community stability (as presently defined by the Forest Service) may, in fact, be an argument against multi-forest working circles. Two factors contribute to the potential for community instability under Alternative 1: (a) the spatial (geographic) arrangement of the National Forests; and (b) the probable nature of harvest schedules for multi-forest working circles.

The preliminary analyses indicate that harvest schedules for multi-forest working circles will produce a cutting pattern that involves the sequential, rather than simultaneous, harvesting of merchantable timber from the component National Forests. Cutting activity would tend to be concentrated on one forest at a time (*table 1*). Harvest levels on Forests within a multi-forest working circle would be highly erratic (*fig. 1*). Fluctuations in harvest patterns could be dampened by imposing scheduling constraints. But in doing so, the increases in total programed allowable cut would be diminished.

Because a multi-forest working circle would likely involve a relatively large geographic area encompassing more than one timbershed, the resulting sequential harvesting pattern (or highly fluctuating pattern in terms of a single National Forest) could lead to a severe stress on community stability. The periodic, major shifts in harvesting activity could force local timber industries to close down or drastically reduce output when cutting activity shifted away from their locality in the working circle. The high transportation costs of hauling a long distance would prevent outlying processors from being competitive in the bidding for stumpage.

Costs from the shifting in cutting activity would be realized in two manners. First, the economic base of many communities might be jeopardized when processing facilities are periodically forced to shutdown or reduce output. Second, shifts in cutting activity among component National Forests would force a rearrangement of Forest Service timber management personnel within the working circle. A normal timber management staff could not be justified on the National Forests during the years of little harvesting activity. In effect, the Forest Service would be adding to the "feast or famine" impact on dependent communities through its fluctuating personnel requirments.

Since funding for National Forests is, in part, a function of the level of harvest activities, shifts in these activities could jeopardize both nontimber management and timber investments. This would serve only to magnify an already existing problem of

Table 1—*First decade allowable-cut levels before and after combining*

National Forest	Individual calculations[1]		Combined calculation[1]	
	Mm Cu Ft	*Mm Bd Ft*	*Mm Cu Ft*	*Mm Bd Ft*
Malheur	342.38	2248.65	479.13	3156.18
Willowa-Whitman	367.11	2169.97	158.43	830.88
Umatilla	313.97	1843.26	396.63	2397.18
Total	1023.46	6261.88	1034.19	6384.24

[1] Computed using a 12-decade conversion period.

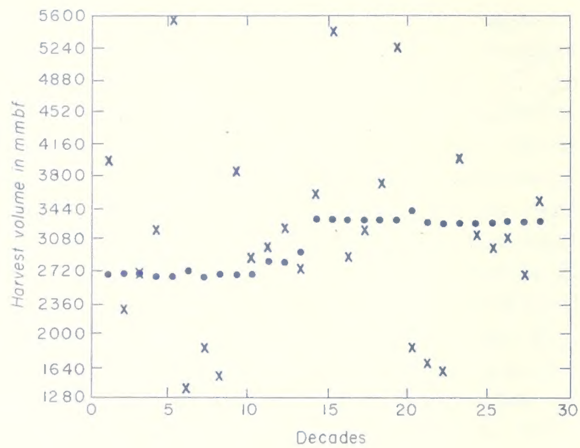

Figure 1—Hypothetical harvest schedules for the Klamath National Forest, California. • indicates allowable cut when the Klamath schedule is determined independently; x indicates allowable cut when the schedule is determined in conjunction with six other forests.

deficiencies in the Forest Service funding process.[5]

The anticipated detrimental impacts of Alternative 1 outweigh the possible benefits. Costs incurred through community instability and budgetary disruptions could be significant. Benefits, in terms of an increased allowable cut, can be expected to be insignificant.

Alternative 2
Formal Multi-Ownership Working Circle

In recent years, multi-ownership units have again been proposed as a potential framework for timber management planning. Within the policy constraint of even-flow nondeclining yield, it seems likely that a formal and binding multi-ownership arrangement would be necessary. Without some form of contractual control over the timber harvest levels on non-National Forest land within the planning unit, even-flow, nondeclining yield could not reasonably be expected to be maintained.

Formal multi-ownership units were first proposed in the 1930's as a means to influence forest management practices on private lands (Adams 1952; Stevens 1958). In 1944, the efforts to impose Federal regulation culminated in the passage of Public Law 273–Sustained Yield Forest Management Act. The act empowered the Secretary of Agriculture to establish cooperative sustained yield units comprised of private and National Forest lands. The arrangement was designed to be mutually beneficial–management on the private land would be subject to Forest Service regulation and management standards, and the private landowners would have exclusive rights, at appraised price, to Forest Service timber sales within the unit.

Several cooperative sustained yield units in several Western States were proposed, but only one of the proposals survived the public hearing process required by law. Primarily, the criticism of cooperative units came from timber processors who claimed that such arrangements would create an unfair advantage (in terms of supply security) for the firms under the agreement. Small sawmill operators who owned no land also felt discriminated against because they were automatically precluded from entering into a cooperative arrangement. Communities near the proposed cooperative units contended that the exclusionary effects of such units would jeopardize their economic well being by virtually drying up the source of stumpage for the sawmills that served as the primary source of employment.

The Shelton Cooperative Sustained Yield Unit, created in 1946, brought under joint management 111,000 acres of the Olympic National Forest and 226,000 acres of industrial forest land owned by the Simpson Timber Company in northwest Washington. The Federal land was predominantly old-growth and the Simpson land was essentially cutover. Simpson would have faced certain shutdown of mills in the area without the additional stumpage provided by the agreement.[6]

The joint annual allowable cut was eventually set at 135 million board feet. Mason and Henze (1959) point out that the annual allowable-cut levels on the National Forest and Simpson lands, if calculated independently, would have been 60 and 30 million board feet, respectively. The creation of the Shelton Unit generated an allowable-cut effect of 50 percent.

Criticism centering on the issues of equity and government regulation eventually served to cancel further consideration of cooperative sustained yield units. In spite of the potentially significant increases in allowable cut from this type of formal arrangement, there is no reason to assume that cooperative units would receive a more favorable public reaction than they did 25 years ago.[7] It is unlikely that a private timber company willing to enter into such an arrangement could be found. In contrast to Alternative 1, the positive effects (in terms of allowable cut) of Alternative 2 would be significant, but the framework is neither socially acceptable nor politically feasible.

Alternative 3
Regional Planning Units

An alternative to larger working circles within the even-flow constraint is to establish regional planning units based on an informal multi-ownership administration. Regional planning units would be delineated by criteria, such as biological zones or government boundaries. For instance, a logical planning unit

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[5] Zivnuska, John. 1974. *Forestry investments for multiple uses among multiple ownerships types.* (Unpublished paper, on file at Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.) Worthington, Richard. 1975. *Some sustained yield issues.* (Unpublished paper, on file at Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.)

[6] Adams, Thomas C. 1952. *Cooperative and federal sustained yield units–a problem in resource management.* (Unpublished Ph.D. dissertation, on file at University of Michigan, Ann Arbor.)

[7] Personal communication with David Cox, Industrial Forestry Association, and with Russ Fredsell, Western Wood Products Association.

could be the Douglas-fir region of northern California.

Rather than an even-flow, nondeclining yield, National Forest harvests would contribute a planned proportion of the total cut from a planning unit. Planning of the cut could be on a 10-year basis, updated every 5 years. The process of determining the proportion of total cut contributed by the National Forests would combine inventory and productivity appraisal, market assessment, and political negotiation. On the basis of forecasts of private sector harvest activity, yield potential on National Forest land, and forecasts of demand, the Forest Service would propose the proportion of cut from its land within the planning unit for the next 10 years. Public response would be invited on the initial proposal. The Forest Service would then negotiate with the timber industry and municipalities within the planning unit to determine a mutually-acceptable harvest proportion.

Forest Service timber-management decisionmaking currently operates within this framework—in effect if not in design. While the even-flow constraint implies a rather rigid management position in theory, flexibility in Forest Service decisionmaking exists in response to case-specific circumstances. Regional planning units administered on an informal multi-ownership basis would explicitly incorporate flexibility and responsiveness to regional circumstances. In terms of timber supply, total harvests probably would increase because of the absence of an even-flow constraint and the high demand for stumpage.

The concept of informal regional planning units suffers from at least three significant weaknesses:

1. Difficulty in forecasting private sector harvest activity. Without direct control over private sector harvest activity, the Forest Service must rely on forecasts to determine the appropriate proportion of National Forest harvests. Accurate forecasting of private sector harvest activities has traditionally been a difficult if not unsuccessful task.

2. Socially inequitable distribution of risk. Given a multi-ownership land base and the absence of an even-flow constraint, timber management theory requires that the western National Forests supply most of the harvested timber until the old-growth is liquidated. Less timber would be scheduled for harvest from the industrial forests until they are restocked and reach maturity. The public, through the Forest Service, would be the dominant risk-taker, in terms of the available timber supply, after the National Forest old-growth is liquidated. There would be no assurances that industrial lands would be adequately restocked, managed, and harvested during years when National Forests lacked enough merchantable timber.

3. Limited public acceptability of programed negotiation with the timber industry. An informal arrangement calling for a closer relationship between the Forest Service and the timber industry may meet considerable resistance on the part of environmentalists and other nontimber interest groups. Public acceptance of such an arrangement would probably be enhanced by provisions insuring adequate representation of nontimber viewpoints in the negotiation process.

Teeguarden (1974) discussed a formal regional planning framework first proposed by the National Academy of Sciences. The proposal is to establish public corporations to function as regional forest management agencies. Leased or contracted private land and public land would be managed under a coordinated planning-budgeting system. Allowable cuts would be determined on a multi-ownership land base so the total cut could be expected to be higher.

The proposal has advantages as well as disadvantages. Direct control of private sector harvest activities can be exercised, but program costs of leasing lands and establishing a public agency could be high. Other limitations include the complexities of resource regulation by a superagency with authority overlapping that of other agencies, and the trend toward centralized government planning.

AN ACE APPROACH TO OPTIMAL WORKING CIRCLES

An orderly, efficient transition to a new system of working circles depends upon the establishment of a criterion of optimality. A criterion that defines the optimum size of working circles, on a case by case basis, provides a rationale for change. In the absence of a definitive rationale, the determination of the size of a working circle reduces to an undirected response to external pressures and circumstances.

Alternatives 1 and 2 are oriented toward the capture of the allowable-cut effect as a motivation for larger working circles. With this orientation, a logical criterion for optimality is the maximization of the cumulative ACE subject to appropriate constraint considerations. Initially, the entire National Forest timber production land base must be delineated into a set of land units according to criteria such as stand composition. If not operating under Alternative 1, non-National Forest land would be included in the land base.

The objective is to partition the set of land units in such a manner as to maximize the total allowable cut (i.e., maximize the cumulative ACE) subject to constraints. The optimal partition defines the boundaries of the optimal set of working circles. A single working circle consists of one or more land units. The optimal partition must be defined such that no working circle boundaries overlap and the sum of all working circles is equal to the total of all land units.

Consistent with the traditional concept of working circles as planning units based around a marketing center (i.e., central processing facility and product distribution point), a requirement of the optimal partition must be that at least one marketing center be located in each working circle. Designation of all marketing centers within the total landbase reduces the number of feasible partitions. Other considerations influencing the optimal solution could include cost limits and supply requirements. Additional constraints serve to further limit the number of feasible partitions.

The most apparent attribute of this approach is that it would ascribe a more rational method to the gerrymandering of working circles under Alternatives 1 and 2. This approach would also maximize the allowable cut for the National Forests within the limits established by present timber management policies (i.e., even-flow). But this may not be considered meritorious by those who feel that Forest Service timber-management policies should be altered. But it must be construed as a least-resistance alternative from the point of view of Forest Service planners. The ACE approach suffers from the same shortcoming as Alternatives 1 and 2; it attempts to maximize allowable-cut levels by capitalizing on a harvest flow constraint (even-flow) that serves to hold down cut levels in the first place. It is a process of inherent suboptimization.

CONCLUSIONS

Further increases in the size of working circles would require a significant departure from present Forest Service timber-management policy. Present policy, as exemplified by even-flow, nondeclining yield, has a paradoxical impact on the issue of larger working circles. Although the primary justification for larger working circles—allowable-cut effect—is peculiar to present policy, requirements necessary to maintain even-flow make the timber supply effects virtually unattainable. Present policy could be maintained under Alternative 1, but the increase in timber supply would be insignificant. Under Alternative 2, the potential impact on timber supply could be highly significant, but the contractual arrangements necessary to maintain present policy make the alternative infeasible. Harvest-level fluctuations brought on by larger working circles could foster instability in timber-dependent communities.

The Forest Service can either discontinue further consideration of changes in the present working circles structure, or it can alter present policy to enhance the feasibility of alternatives. The abandonment of both even-flow and the orientation toward community-level economic stability give rise to consideration of multi-ownership regional level planning units. Under a regional format, potential yield levels could be expected to be higher even though ACE would no longer be operating. A more drastic departure from present policy would involve the abandonment of the biological approach to timber management exemplified by the traditional sustained-yield format. Some economists[8] have proposed replacing the biological approach with an economic approach.

In determining which option to pursue, the major consideration must be the cost of abandoning present timber-management policies. To date, the Forest Service has felt the costs to be restrictively high. An additional consideration is that, while there exists a theoretical potential for an increased allowable cut through alternative planning unit arrangements, the magnitude is mitigated by factors not previously considered. Western National Forests are indeed a virtual depository of old-growth, but accessibility to this stumpage is reduced by several obstacles. Limitations imposed by appropriated budgets have kept the actual harvest levels below the allowable levels. Given the present status of the National Forest road network and the costs of alternative transportation systems (i.e., helicopter logging), some old-growth stands will not be physically accessible for years. Accessibility is further reduced by land-use zoning. The timber production landbase is steadily declining as pressures increase to create wilderness and recreation areas. Other blocks of productive lands are being removed because of ecological or environmental restrictions. The net impact of these barriers is that increased harvests may be more a theoretical possibility than a field-level certainty.

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[8] Ledyard, John, and Leon Moses. 1975. *Dynamics and land-use: the case for forestry.* (Unpublished report, on file at Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.)

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VANDALISM AND OUTDOOR RECREATION: symposium proceedings

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Resource managers, law enforcement officers, designers, and social scientists provide 24 papers giving an overview of vandalism on outdoor recreation areas; a measure of the difficult control problems which must be solved; some insights for design of buildings, fixtures, and site layouts to reduce or repel vandalism; and a profile of vandals, with respect to the potential for reducing their activities through understanding of social-psychological factors. Recommendations prepared by panelists and symposium participants summarize the views presented and suggest measures for control of vandalism on outdoor recreation areas.

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Retrieval Terms: outdoor recreation areas; vandalism; law enforcement; design; social factors.

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VANDALISM AND OUTDOOR RECREATION: symposium proceedings

Sam S. Alfano Arthur W. Magill
Technical Coordinators

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PREFACE

Vandalism is taking an increasingly big bite out of the funds needed for protection and maintenance of recreation facilities in southern California. The problem is not limited to the southern portion of the State or even to California as a whole--it exists nationwide. In 1974, $1.5 million was spent to correct vandalous damage and littering on the 17 National Forests in California, but $7.5 million was the cost to the entire National Forest System. Agencies other than the Forest Service are also paying the cost of vandalism. The California Department of Parks and Recreation reported $87,000 worth of damage in 1975, but because considerable vandalism goes unreported, actual annual costs have been estimated as high as $180,000. The U. S. Bureau of Land Management has estimated damage as high as $250,000 per year; although that is much lower then the Forest Service's costs, the Bureau has fewer facilities and they are more widely distributed. In general, vandalism is increasing for municipal, State, and Federal agencies as well as for private landholding companies.

Resource managers throughout the nation are searching for the meaning behind vandalous acts, hoping that through reason and understanding, they can find ways to stop the seemingly endless destruction, theft, and littering. The Outdoor Recreation Vandalism Symposium, held March 26-27, 1976 at Santa Barbara, California sponsored by the Los Padres National Forest of the Forest Service and the Southern California Section of the Society of American Foresters, represents a step toward an organized, interdisciplinary approach to the search for solutions. The symposium has drawn upon the expertise of foresters, sociologists, criminologists, architects, park planners, psychologists, landscape architects, and recreation technicians to define the impact of vandalism on (1) the physical resource and the user public, (2) the problems of law enforcement, (3) the opportunities for control through facility and site design, and (4) the socio-psychological profile of vandals and the potential for social control.

The "man-on-the-ground," the recreation resource manager, daily faces the consequences of vandalism. He usually regards acts of vandalism as "senseless" or "wanton" and cannot understand why some people deface or destroy facilities provided to give them pleasure. In this collection of papers, several "men-on-the-ground" offer their views of the destruction wrought by "phantom" vandals and of "types" of vandalous acts. Vandalism is variously described as littering; disturbing the peace; damaging or destroying vehicles, buildings, or other property; starting wildfires; chopping down or mutilating trees and shrubs; theft; and defacing objects with graffiti. Managers have tallied the costs of vandalism, and they have been innovative in dealing with the problems, but they admit to a lack of sound solutions that are generally applicable. They are seeking assistance in effective control of vandals.

Resource managers work closely with law enforcement officers. Unfortunately, catching a vandal is not simple, for all too often, the act is unobserved and the vandal is gone before an officer arrives. Several resource managers, a law enforcement officer, and a magistrate have expressed, in these proceedings, their frustration in dealing with vandals. Some officers suggest stronger police control and others suggest avoiding a "hard approach to law enforcement. Some agencies have trained resource managers to be law enforcement officers, whereas other agencies do not want managers to assume the responsibility. The obviously conflicting viewpoints strongly suggest the need for greater understanding and more uniformly applicable approaches to law enforcement.

Architects, landscape architects, and engineers are faced with the dilemma of designing sites, buildings, and facilities that are vandal-proof yet attractive and serviceable enough to not invite vandalism--more desirably, that are so "in tune" with human needs that vandalous acts do not happen.

The sociologist-psychologist perceives vandalism as a social problem that is symptomatic of society's failure to provide for the basic human needs of a segment of the public. Unfortunately, no universal answers are available now or likely to be. Understanding of the diversity of individual motivation--of both the vandal and the manager--is a necessary step toward discovery of diverse solutions.

By summarizing the papers of the panels in each problem area, and securing audience interaction, we have developed a number of recommendations.

We hope that resource managers and others will try to follow the recommendations.

Furthermore, we hope they will record and report successes or failures, thus giving some measure of the results of the symposium. Such feedback will help to determine the desirability of future meetings, and may also suggest additional research objectives.

This symposium on vandalism brought together representatives of the Forest Service, U.S. Department of Agriculture, and the Society of American Foresters. Paul Rich, educational chairman, Southern California Section SAF, served as symposium co-chairman. The following National Forest public information officers served as panel moderators: Elliott Graham, San Bernardino; David A. Kimbrough, Angeles; Grover Payne, Cleveland; and Edward Waldapfel, Los Padres.

RECOMMENDATIONS

There are currently no universally applicable solutions for vandalism. Develop solutions to meet the demands of specific locations and conditions.

Public Involvement and Planning

● Provide opportunities for the public to express their opinions and ideas about outdoor recreation planning. It may be important to involve users in the development and maintenance process.

● Do comprehensive site planning on the site, with input from site managers, designers, and law enforcement specialists. Use opinions and ideas from the public in the planning process.

Environmental Education

● Explain to visitors how various activities violate human rights or damage or destroy facilities and natural resources.

● Develop programs to show visitors how to use various recreational facilities and related natural resources in a manner that increases their enjoyment without damaging property and resources or violating the rights of others.

● Use schools and mass media to inform all levels of the public about proper and considerate uses of outdoor recreation areas. The success of educational programs is dependent on succinct messages that avoid professional jargon, on proper audience identification, and on selection of the best media or other conveyance to reach the desired audiences.

● Initiate news coverage by recreation personnel on items of public concern without relying on the news media to write the articles.

Manager Attitudes, Involvement, and Training

● Secure personal involvement of management personnel in solving the vandalism problem. It is essential for managers to realize that they may actually encourage vandalism through accepting poor site and facility design, providing recreational opportunites that are meaningless to users, or failing to understand and relate to the needs of users.

● Consider the full range of methods available to managers for reducing the entire problem of deviancy.

● Avoid rules that merely serve managers' convenience, and design, plan, and manage to satisfy the interests and needs of the user public.

● Develop and use training programs to indoctrinate full-time and part-time personnel in policy, law enforcement, and personal approaches to users.

● Set up a sound training program and an effective career ladder for outdoor recreation personnel.

Regulation, Cooperation, and Law Enforcement

● Establish and use a uniform code of regulations for all agencies in a coordinated effort to reduce vandalism.

● Set up annual review by law enforcement and resource agencies of their respective authorities and responsibilities to assure a clear understanding of their respective roles.

● Increase availability of law enforcement personnel while minimizing costs by utilizing the Sheriff's Reserve Deputy program. Reserves are volunteers who work with regular Sheriff's Deputies during weekends and other heavy workload periods.

Improve Agency Image

● Promote a favorable public service image by

improving employee image of the agency (build stronger *esprit de corps*)

explaining to visitors the reasons for agency actions

providing complete outdoor recreation information at each recreation area

maintaining a low profile but fair, firm, and impartial policy in law enforcement.

Court Actions

●Take law enforcement action on obvious violations.

●Make the names of convicted vandals and their punishment known through the media.

●Encourage courts and magistrates to sentence misdemeanor offenders to work on outdoor recreation areas.

Management Control Actions

●Reduce conflict between types of recreational activity (groups vs. single families, motorboats vs. sailboats, fishermen vs. water skiers, etc.) by assigning them to separate areas.

●Provide firewood at the campground whenever practical.

Provide safe areas for target practice with firearms.

●Provide free interpretive materials at the site for the use and enjoyment of visitors.

●Provide evening campfire programs.

●Use signs that convey positive messages.

●Establish or continue the incentive litter control program to encourage positive campground behavior by both children and adults.

Controlling Access

●Issue permits or use a reservation system to identify individuals, families, or groups, thereby increasing control and making users accountable for their actions.

●Where possible, use entrance stations to control access to recreation sites.

●Charge an entrance fee for site maintenance or require a cleanup deposit, to be forfeited if users fail to leave a clean camp.

●Provide gates to control entry when a campground is full or after 10:00 p.m., but which permit departure in the event of an emergency.

Increase Visibility and Surveillance

●Design sites to be visible to patrolling officers.

●Increase the visual presence of rangers, caretakers, or police by

scheduling work hours to coincide with peak use periods and times of greatest conflict

avoiding regular patterns of patrol

using the task force concept (3 or 4 officers at a time) to saturate problem areas.

●Use volunteer or other manpower programs to provide campground hosts (caretakers).

●Consider hiring a known vandal, who is respected by his group, to be a caretaker or patrolman.

Design

●Do not overdesign; less elaborate facilities would be adequate.

●Design toilet buildings to

meet the needs of the user

minimize vandalism.

●Design two-unit vault toilets with a minimum of 400 square inches of venting.

●Promote awareness by both producer and consumer that some manufactured products (motorcycles, jet skis, snowmobiles, hang gliders, etc.) are potentially destructive to the resource and annoying or intrusive to nonusers.

Research

●Continue research and testing of design concepts.

●Re-evaluate the role of private enterprise in building and operating recreational developments on public lands.

●Conduct practical, on-the-ground research on the diversity, intensity, causes, and potential controls of vandalism on outdoor recreation sites throughout southern California and if possible the entire southwest. The various agencies concerned should cooperate on research projects.

●Conduct research to help solve problems of dispersed recreation, particularly vandalism.

THE VIEW FROM THE FIELD

Vandalism---an Overview

George A. Kenline[1]

In the Bronx Zoo, New York, there is a sign above a window that says, "See the most destructive animal alive!" People rush to the window to have a look. The window is equipped with a mirror. The experience is both revealing and condemning. Man has been and continues to be destructive in many ways. I would like to explore with you some of the ways man, woman, and child express themselves when using the mountain areas of southern California. These expressions of behavior will be labeled as acts of vandalism, that is, the illegal destruction or defacement of property belonging to someone else.

The mountains of Southern California are unique to millions of people who find them a welcome contrast to the blighted urban setting in which they live. The mountains are still a place where you can see green trees, rocks, blue sky, fresh water and stars at night. Most are located within 1 hour's travel of foothill communities and within 2 1/2 hours of the Los Angeles metropolitan area.

Historically these mountains have sat as an island above a sea of desert, brushland, smog, noise, and congestion. But the late 1960's and early 1970's saw the character and quality of the mountain experience change. And the modern camper bears little resemblance to his forefather. He's well equipped, highly mobile, and leaves more than his footprints.

Assuming this is a representative group, let me ask you some questions. Do you throw your trash into your neighbor's yard? Do you clutter up his flower beds with empty beer cans and pop bottles? Do you litter his nice green lawn with used tissues, disposable baby diapers, newspapers, paper bags, and so forth? Do you chuck rocks, bottles, and inner tubes into his fish pond? It is most unlikely that you do. You doubtless have respect for his property and know that he would object to such behavior. Since you respect your neighbor's property and would not think of littering it with junk, do you have the same respect for public and private lands in the distant mountains? Apparently not everyone does, because yearly, like a plague of locusts, careless visitors not only litter and trample, but worse still, deliberately destroy and deface those very natural features which they journey to see and enjoy.

Let us consider some of the forms and types of vandalism we in the field see recurring on a season-to-season if not a day-to-day basis. And for purposes of discussion, let's try to give them motive and meaning.

The first type of vandalism is done in the course of, or in order to, acquire money or property. This includes junking or stripping for resale, collecting souvenirs, and just plain looting.

A second type is damage done as a conscious tactic to advance some end. The end in mind might be to draw attention or gain publicity for a particular cause.

A third type uses property destruction as a form of revenge by someone who feels unfairly treated. This form of vandalism is much safer than punching the ranger in the nose.

A great amount of damage is carried out by preteenage children as part of their play activities. Many parents regard the campground as a place where children can play in a healthy environment. The dangers of the city are left behind; nothing can hurt the children, and there is nothing the children can hurt in return. The burdens of parental supervision can be traded for quiet hours of privacy as children run off to play by themselves. An the children are alone, much more so than in their own neighborhoods. The open street is replaced by screening woods. Watchful neighbors are exchanged for indifferent strangers dutifully following the rule of noninvolvement that prevails in public places. Preadolescent children probably feel no sense of responsibility toward park facilities, and their predominantly urban upbringing provides few lessons in behavior appropriate to the natural environment. Under these circumstances, it is almost inevitable that damage will occur, motivated by curiosity and often by the spirit of competition.

The findings of a study done by Campbell, Hendee, and Clark in 1968 at a Pacific Northwest developed site are typical of our mountains. Here is their account:

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[1] Recreation Assistant, Big Bear Ranger District, San Bernardino National Forest, Forest Service, U.S. Department of Agriculture, Fawnskin, California.

Two boys... approximately 12 years of age, came to the campground accompanied by their mother and three younger siblings. Their father remained in the city and visited only on weekends, a fairly common arrangement. Upon arrival, the boys immediately left their mother, who was quite happy to be relieved of entertaining her two children. During the first two days in camp, the boys wrote obscenities on the wall of one washroom, plugged the toilets in a second, broke bottles in the beach area, chopped down a tree, tore down eight metal signs on the nature trail, and became lost overnight in the woods. Other than their overnight adventure, their activities went completely unobserved by other campers or campground personnel. One should not conclude, however, that these boys were naturally malicious. When one of the park rangers suggested they use part of their free time picking up trash and litter, they plunged into the activity with equal enthusiasm.

For destructive play, the old adage, "blame the parent, not the child," has more than a grain of truth. Considerable money could be saved each year if parents assumed greater responsibility for the activities of their children while in public parks. [2]

Much damage can be attributed to unthinking but well-intentioned adults. For example, campers sometimes solved the persistent problem of scarcity of firewood by theft from other campers or by cutting down a nearby tree, with no thought to the conservation implications of the act. Nails were hammered in trees to store camping equipment off the ground; cars and trailers were driven off parking pads and into vegetated areas for the sake of convenience; fires were built outside fireplaces by persons unaware of danger to timber-dry woods; trailer sanitary tanks were emptied in dumping stations clearly marked "closed" or "full" as people sought short-run solutions to their immediate problems. The point is that basically responsible but ill-informed and temporarily inconsiderate people create many problems in public parks.

The final type of vandalism we will consider can't be explained any other way than to say it is malicious mischief in which persons or groups of persons combine hostility with fun. This type of vandalism is encouraged to a degree by our society. Events such as Halloween, fraternal initiations, semester breaks, and the aftermath of sporting events are examples. And the same kind of mentality accounts for what is known as "graffiti," the crude writing of names, slogans, obscenities, and vulgarisms on facilities or natural features. Graffiti differs from other forms of vandalism in that it is expected (for example in a public restroom). Lavatory attendants and caretakers of public buildings regard the cleaning of walls as part of their daily routine.

Why must a public toilet cost $28,300? Simply because the ladies and gentlemen who use it often are not "ladies" and "gentlemen." You might say 'a comfortable one can be built for half the price.' True, but public restrooms must be vandalproof. We are forced to build them to withstand vandalism of the most senseless kind, and it costs more. Lavatories are of heavy cast iron, shower heads have tamperproof bolts, lighting fixtures have double protection against breakage, showers are activated by buttons because shower handles would be torn off within a few days or perhaps before the building could be completed. The restroom is made of concrete block construction because some people have a habit of stripping lumber from wooden structures.

Vandalism is costly. But any figures are grossly understated: the cost of services and benefits foregone until facilities can be made operational again, of maintaining patrols and security forces, and of many other intangibles are seldom included. For example, vandals typically make public phones unusable. Besides the property damage, there is a toll in human tragedy here. A young girl died when her father was unable to summon a doctor from a public telephone damaged by vandals.

I'd like to share with you my first experience with vandalism as a public employee, and maybe shed some light on who does this sort of thing. On the Cleveland National Forest, along the old Highway 80, Ellis Wayside Rest is administered as a day-use facility by the Forest Service. The site is on a hillside covered with boulders festooned with graffiti. On a Sunday afternoon the Ranger, who had made up his mind to catch someone, went there and waited. It wasn't long before a car pulled up with a man and woman inside. The woman got out, opened the trunk, removed paint and brush, and headed for the rocks. After she painted her name on a large boulder, the Ranger intercepted her at the car. She was very embarrassed, and rightly so. She was a mature, well dressed, and well

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[2] Campbell, Frederick L., John C. Hendee, and Roger Clark. 1968. Law and order in public parks. Parks and Rec. 3 (12) 28-31, 51-55, illus.

educated woman. Her husband, a Navy captain and ship's commander in San Diego, sitting in the driver's seat, was at a loss for words. Why had she done it?--she had always had the urge but never before the opportunity. This one experience points up the diverse backgrounds and ages of the so-called vandals.

What is behind it? Many explanations have been given. "All crime is up, everywhere, and this is just part of it," have said some authorities. Vandalism and Violence[3], a special report developed by the staff of Education U.S.A., points to improper instruction and adult behavior as contributing factors: "The Boston Tea Party is often held up to students as a 'patriotic act,' a sort of punishment for the British in retaliation for an onerous tea tax. Yet what happened was pure vandalism perpetrated by grown men."

When taken together, the various reasons given seem to indicate that vandalism is often a protest. Stanford University Professor Philip G. Zimbardo[4] explains: "Vandalism is rebellion with a cause." The cause, he says, is "social indifference, apathy, the loss of community, neighborhood and family values." It is true that practically everywhere young ones see loss of values--lying, cheating, and hypocrisy are rampant, even among world leaders. This breeds hostility in youngsters against "the establishment" and vandalism is one way they vent their feelings.

Indifferent, uncaring parents are perhaps the main cause of vandalism. And this abdication of responsibility by parents is noted in practically every community. As a result, rich, poor, middle class, and both black and white youngsters are all deeply involved in vandalism. A study of more than 3100 teenagers from "every major segment of the Illinois adolescent population" revealed that nearly one in every three had engaged in property destruction!

Wanton destruction by vandals is hurting property owners, increasing the cost of government, pushing up taxes and insurance rates, and adding hundreds of millions of dollars to the high cost of living in America. However, to highlight the law enforcement problems--consider the destruction of municipal property in New York, where there were more than 100,000 complaints of vandalism but only 3216 arrests were made. Many offenders get off with just a light reprimand.

The central reason for nonenforcement is one that applies to vandalism as a whole--the fact that this is one of the most safe and anonymous of offenses. There is no personal complaint, nor any property to carry or dispose of.

Consequently, detection rates are low and most damage is not thought worth bothering about. Although the total cost might be considerable, each individual act is too trivial to respond to in any other way than by ignoring it.

Employees complain, "I don't get it. We give them something free and they destroy it." A feeling of hopelessness has become general. Here's a typical feeling expressed by a recreation worker after reviewing four pages of notes on repairs needed in District developed sites. "It's nothing to get hysterical about. It's a housekeeping problem, a part of managing public facilities. One minute it upsets you, the next minute you think 'that's life.'"

We've looked at a number of examples of vandalism. Maybe we should try to draw some preliminary conclusions as one might do who works with the problem in the field.

1. The property destroyed is much more likely to be publicly than privately owned. This is due not just to the greater opportunities to attack public property, but also to its anonymous nature and symbolic value. The target is depersonalized and not easily identified with the idea "it belongs to them."

2. Some patterning in the physical characteristics of the target is also apparent: the property tends to be derelict, incomplete or badly kept. Again such property might be seen as fair game and not really belonging to anybody.

3. Areas of high vandalism can be distinguished by their social characteristics. Sites close in and within easy access to lower income groups receive more than their share of vandalism.

4. Studies of the social characteristics of the offender are important to counteract the image of homogeneity which assumes the existence of something like a "vandal type" responsible for all sorts of vandalism. Clearly no such personality type exists.

Wells, Elmer. 1971. Vandalism and violence: Innovative strategies reduce cost to schools. Education U.S.A. Special Report. 59 p. Natl. Sch. Publ. Rel. Assoc., Washington, D.C.

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[4] Zimbardo, Philip G. 1973. A field experiment in autoshaping. In Vandalism. P. 85-90, illus. Colin Ward, ed. Van Nostrand Reinhold Co., New York.

5. Groups of young people in late adoles-
nce, enjoying the relatively inexpensive bene-
ts of public facilities, are prone to partici-
te in malicious, apparently senseless vandal-
m.

How can this rising tide of vandalism be emmed? What is needed? Many efforts are ing made to reverse the tide. Difficult--break plastic is replacing glass in win-ws. Hard-finish epoxy-resin paints that sist markings with felt-tip pens, lipstick, d crayons are being used on interior walls. w buildings are being built like fortresses, th few, if any, exterior windows. Alarms, nces, night lighting--all of these measures d more have been employed. Yet vandalism creases.

> In the final analysis parents must be parents. They cannot slough the job onto someone else. And they very definitely do have an obligation to ...discipline.... Its chief value lies in strengthening the (personality) so that the adolescent can deal adequately and independently with his inner drives and with outer pressures. It prevents the child from becoming a victim of anarchic impulses, narcissistic indulgence, and a false sense of omnipotence. The parent must employ this discipline in a manner that will lead to self discipline."

I would like to conclude by reading from an article in the San Bernardino Sun, titled "Vandalism may not be all bad." Federal officials here are poking holes in the theory that vandalism is all bad. They have found that bullet-riddled signs are stolen less often than unscarred ones. After losing four or five brand new off-road signs in as many months, Bureau of Land Management rangers decided early this year to punch holes in the signs before installation. "The signs with holes just don't look as good to thieves who want them for their wall at home. Before holes, the signs lasted about 10 days, since becoming holey they've stayed up to three months."

Vandalism on the Santa Lucia District

John Blake[1]

The staff of the Santa Lucia District of e Los Padres National Forest would like to ink that this District has a better forest er than some of the other Districts of Forests. r vandalism problem has been small in the past, t it is increasing even though our District is ite isolated from large population centers. e nearest and largest towns are San Luis Obispo d Santa Maria, but both are relatively small. ree State highways and one interstate highway ovide limited access to the District.

Despite generally average-type visitors, a vorable location, and limited access, our total sts due to vandalism came to $4,213 during 75. Litter and trash pick-up costs amounted $18,700. The predominant types of vandalism at we have experienced are: (1) shooting,) chopping, (3) graffiti, and (3) stealing. The tent to which public facilities can be damaged is evident. Rifles, shotguns, and pellet guns have been used to riddle toilet-walls, garbage cans, signs, and even trees. People without guns have used rocks, sticks, axes, large hammers, and even vehicles to destroy buildings, tables, signs, and even gates made of heavy metal pipe. People have dumped litter and garbage on the ground, stolen tables, and used all types of wooden facilities for firewood. Obviously, wood structures are easily damaged, but we have also learned that fiberglass is a poor material for constructing campground fixtures.

The following measures may help to discourage vandalism in wildland areas:

1. Reward persons supplying information leading to the apprehension and conviction of persons committing vandalous acts, by giving them the fines imposed against the guilty persons

2. Require forest visitors to register before entering recreation sites.

3. Designate shooting areas for people to use. Cooperation with sportmen's clubs might

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[1]Recreation Technician, Santa Lucia Ranger strict, Los Padres National Forest, Forest rvice, U.S. Department of Agriculture, Santa ria, California.

contribute to successful establishment of shooting areas.

4. Permit senior citizens free use of campsites in return for watching the campground and maintaining the area. Full-time occupancy by responsible persons may discourage vandalous acts.

5. Establish positions for the handicapped and the senior citizen to act as a combination caretaker-registrar for campgrounds.

6. Use Visitor Information Service techniques through public presentations to discourage vandalism.

7. Utilize the mass media (TV, radio and newspapers) to disseminate information to the public concerning vandalism and to campaign against it.

Vandalism on the Mt. Pinos District

James Hunter[1]

The Mt. Pinos Ranger District is located 15 miles west of Interstate Highway 5, approximately 1 hour driving time from the fringe of the Los Angeles metropolitan area. The District includes nearly 500,000 acres of land which has extremes in topography, as well as weather. The elevation ranges from 3000 feet to 8831 feet at Mt. Pinos, the highest peak on the Los Padres National Forest. Temperatures range from below freezing in the winter months to 100 degrees and above during the dry summer months.

Because of its high elevation, the area becomes a snow-bunny haven during the winter months. Thousands of visitors from the Los Angeles basin flock to the snow-covered slopes. Use by 10,000 to 20,000 visitors during a winter weekend has a tremendous impact on existing recreation facilities. For example, garbage-can lids are used regularly to slide on, and garbage cans are stolen or damaged beyond repair. Most important, tons of litter are left on the slopes to be cleaned up by District personnel. In 1975, use attributed to snow-play was 53,100 visitor days, and the cost of litter cleanup was $30,000. Vandalism costs were $14,430; the costs of the closely related total law enforcement needs were $11,382.

Another major dispersed recreation activity is offroad motorcycle use. Last year this activity accounted for 250,000 visitor days. On special occasions, such as permitted "enduro" events, some 2000 to 3000 people are attracted. Fortunately, the organizers of these events are required to provide necessary sanitation facilities, as well as removal of refuse. The majority of offroad vehicle use, however, is not by organized groups. It is the unaffiliated users who are responsible for the considerable litter and vandalism problems of the District. Between 20 and 30 cubic yards of trash are removed from Ballinger Campground every week.

Considerable damage can be done by two-wheel- and four-wheel-drive vehicles during the wet periods of the year. No determination has been made, at this time, of whether this damage is inadvertent or caused by those enthusiasts who want to pit their driving skills against the elements. The rutted roads and scored hillsides soon become water collection troughs that accelerate soil erosion. The impact of these vehicles can be judged by the fact that their owners accounted for 104,358 visitor days of use in 1975.

Acts of negligence and vandalism are not wholly attributable to offroad vehicle use. Campers also do their share of destruction, such as tipping over toilet buildings, breaking stove tops, building firerings, and destroying campground signs. A total of 250,300 visitor days were attributed to camping in 1975.

In recent years we have noticed a rapid increase in promiscuous shooting. All objects become targets for shooters. Garbage cans, campground entrance signs, visitor registration signs, fireplace chimneys, and toilet doors and vents have to be replaced because of shooting. Some visitors even test their shooting ability by felling a tree by successive

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[1] Recreation Technician, Mt. Pinos District, Los Padres National Forest, Forest Service, U.S. Department of Agriculture, Frazier Park, California.

shots at the trunk. These are pure wanton acts of destruction.

As you can see, we have had our undue share of vandalism. I hope that we can gain some insight on this serious problem so that law-abiding citizens can again enjoy their outdoor recreation experience.

Vandalism in Desert Areas

Mike Wintch[1]

The story of vandalism in the California desert is undoubtedly similar to many others that might be told by Federal, State and local agencies charged with managing outdoor recreation lands and facilities.

In the desert, representatives of the American public in search of recreation have left their mark in the form of "graffiti" on rocks, trees, picnic tables, outhouses, signs, and historical structures. They have blown up outhouses at developed but primitive camping areas, removed or mutilated signs and markers, torn down historic structures for use as firewood, and done about everything else in between.

They have also planned and participated in projects to remove "graffiti" from canyon walls, clean up major recreation areas, remove hundreds of tons of trash, restore historical objects, construct fences around abandoned mine shafts, clean up trash around a small historical site, and about everything else in between.

The vandalism story includes the expenditure of public monies: the $10,000 to replace the blown up outhouse, the $6,500 to replace picnic tables, repair a large interpretive sign and repair another outhouse--all vandalized in one weekend of use at a popular developed camping area--and the inestimable damage to our heritage when historical objects and buildings are torn down and used for firewood. The story also includes the saving of public expenditures in labor costs for the work done by volunteers.

But this traditional story of vandalism is not the one I would like to tell today. Let me share with you two incidents that I think relate directly to the attitude developed by each individual member of the American outdoor-recreation-seeking public--"to vandalize or not to vandalize."

The first took place less than 100 miles from downtown San Diego, adjacent to giant Anza-Borrego State Desert Park, where the Bureau of Land Management has developed three lovely little primitive campgrounds. They are available and well used by those who visit the Lark Canyon-McCain Valley area. Although they can be reached only by dirt roads, they are readily accessible, most of the time, to Dad, Mom, and the kids in the family "flivver."

Recently, a BLM maintenance man, making one of his three-times-a-week trips into the area, encountered, from a distance, a group of "ruffians" raising cain in McCain Valley. Fearing for his own safety and the safety of the other good folk camping in the area, he called on the local deputy to venture up the 10 or so miles of dirt road and restore peace and tranquility. Arriving on the scene in his well-equipped patrol car, the deputy encountered the "ruffians" at close range and suggested they mind their manners and keep their motorcycles on the roads and at a respectable speed. The group agreed to comply so the deputy left. However, on his next trip into the area, the following afternoon, the maintenance man encountered "mayhem" including a heavily damaged outhouse.

The second occurred in the Imperial Sand Dunes, a vast sea of sand some 40 miles long and 3 to 5 miles wide, which has stimulated the development of a unique form of outdoor recreation. Developed in southern California, "duneing" with offroad vehicles is now popular in much of the Southwest.

This popular area located about 45 minutes east of El Centro, may be visited by up to 50,000 people on a single weekend. The dune-buggy enthusiast, with his ultralight, offroad vehicle, can penetrate this entire sea of sand,

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[1] Chief Ranger, Bureau of Land Management, U.S. Department of the Interior, Riverside, California.

and for years, the whole dune area was available to him. Then, on November 1, 1973, the BLM implemented a vehicle management plan that set apart a portion of the Dunes as a natural research area and posted it as closed to all offroad vehicle use.

With no authority to enforce this closure, the Bureau elected, or was forced, to take an "ambassador of good will" approach and attempt to inform and educate visitors so as to gain their voluntary compliance. The newly-formed ranger force began the task of meeting and greeting the people, informing them of why the natural research area had been set aside, assisting in search and rescue, providing emergency medical first-aid, and assisting the stuck or stranded.

A dunebuggy was obtained to allow the Ranger access to the vast sea of sand, not the fastest buggy on the slopes, but a unique vehicle designed to carry litters, first-aid equipment, and rangers trained to assist those in need. An access road is being built along the threshold of the Dunes and camping facilities are being developed. Last fall a temporary Ranger Station was erected to provide a focal point for BLM influence in the Dunes.

Significantly, when the signs were first posted around the closed area, about 95 percent were vandalized the first week. Today, with the same amount of ranger patrol and the same authority, this sign vandalism has been reduced by over 95 percent. When the camping facilities were first developed, a large trash receptacle disappeared. Today it seems unlikel that that will happen again.

The temporary Ranger Station, really a house trailer in disguise, was put in place in early September 1975. This station, located miles from any permanent residence, is not manned at all on weekdays and only part of the time on most weekends. Furthermore, it is not protected by a 10-foot high cyclone fence. Yet today not even a window has been broken.

Could it be that for the individual user's, "to vandalize or not to vandalize" is directly associated with the individual manager's attitude--or more importantly, the management group's attitude--that they are to be thought of first and foremost, as a source of public service and assistance?

Vandalism in the Channel Islands National Monument

Ronald W. Sutton[1]

The degree of isolation enjoyed by Channel Islands National Monument would seem to be a natural deterrent to vandalism. The Monument consists of the two smallest of the eight Channel Islands off the southern California coast--Anacapa and Santa Barbara Islands. Anacapa is about 10 miles from the mainland, Santa Barbara about 40 miles. The islands can be reached by private or commerical boat, but there are no aircraft landing facilities for public use. Anacapa Island is manned year-round and a ranger is on Santa Barbara Island during the summer.

There have been reports of vandalism problems from the "old hands" during previous seasons. In particular, on Santa Barbara Island, people were shooting at the island and occasionally at the ranger station. People came ashore and dug up plants for their home gardens. They investigated the sea lion rookeries, causing stampedes which killed pups too small to get out of the way. There was bad feeling between the commercial fishermen and the Park Service. People created new trails which caused erosion and were unsightly. We felt that we could deal with these problems through law enforcement, if necessary, but we also felt that we could prevent many of them with a strong personal contac program between the rangers and the visiting public--protection via interpretation.

The theory behind this program is simple. The park visitor is in the park because he wants to be there, and he looks forward to an enjoyable experience. However, this same visitor brings with him an urban outlook to a wilderness environment. This outlook is not conducive to an understanding of this new (for him environment, and what he does not understand he may destroy. (Consider a two-year-old child with an electric train. He loves the new toy, but does not understand it and it is soon broken. He may still think it is a great toy,

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but its original purpose is destroyed and its value for others is gone.) If we can create some understanding by the visitor of his new park environment, he will not be so likely to destroy it.

We attempted this by talking to people, morning, noon, and night. We visited them on their boats and passed out litter bags and information sheets. We invited them ashore. We talked about regulations and the reasons for the regulations--how the regulations were designed to protect them and their park. We talked to commercial fishermen about how this was their park and what the Park Service was doing there. We passed out maps of the island and suggested things to do based on the makeup of individual groups. We held impromptu nature walks, often several a day. We set up displays of things for people to touch and wonder about. We tried to contact every individual who came within the park boundary. We gave campfire programs to campers, not on natural history subjects, but on how to take care of a tiny, fragile, one square-mile island--their island. Above all, we talked, talked, talked--to people.

What were the results of this program? It is difficult to say for sure. Perhaps the problems had been overstated. Perhaps the fact that the island rangers had a small patrol boat for the first time lessened some of the problems that existed in the past, but these facts remain: we only had three firearm violations all summer. Five people out of over five thousand disturbed the sea lion rookeries. Only about 200 yards of new trails appeared. Relations with commercial fishermen were good or excellent. Very few people attempted to remove souvenirs from the island. No plants were taken to home gardens. The most interesting fact, however, is that all the violations that did occur were committed by people we had not had a chance to talk to,

This program was carried out by only two people. Admittedly, we had the ideal condition of controlled access to a use area. (There is only one place to land on the island and only one good anchorage, so we were able to get to the visitors.) I believe this kind of program would be useful in other areas where the access is less controlled. The important things are to give the visitor an understanding of the area and of the new environment in which he finds himself and to provide him with the reasons behind the regulations which are designed to protect him and his outdoor recreation area. I believe this is the most important job the "man on the ground" can do, and it is his job--it can't be left to signs and handouts.

Having been the "man on the ground" for the past five years, I would like to share some of my observations on the subject of vandalism. Actually, most of what follows are questions more than observations--questions for which I don't pretend to have answers.

Why is it that a well-maintained recreational facility seems to be more or less free of vandalism? I have seen areas that were in good condition stay that way over long periods of time. At the first sign of vandalism, however, almost total destruction followed in a very short period of time. Can a little cleaning compound and elbow grease at the first sign of restroom art prevent a repainting job a few months later? Would a blowtorch, used to produce some artificual exfoliation of the rock under the first "John loves Mary," prevent a scenic area from becoming an outdoor tabloid created in spray paint? I think so. A good maintenance program that takes care of the little things before they become major problems will solve some of our vandalism problems.

How many times has the reader seen posted regulations that were systematically ignored by recreational visitors and enforcement personnel? I have seen it--thank God, not often. Does this situation lead to a lowering of the value of all regulations in the mind of the visitor? Does this obvious contempt for the posted regulation lead to vandalism? I believe that if we post a regulation we should enforce it, or interpret it to gain compliance, or take it down--we should never ignore it.

I recall a situation in which we were just asking for vandalism. We had a pump house, somewhat removed from the campground, that had frosted reinforced glass windows. The windows were constantly being broken. This vandalism had a pattern; one that I didn't see. First a small hole would be broken in one of the windows, presumably so someone could see what was inside. (There was nothing inside except an electric pump.) Then, in a few days all of the windows would be broken and we would have to replace them, always with frosted, reinforced glass. Couldn't we have put in one pane of clear glass and avoided the whole problem by affording the original curious visitor his look inside? Are there other situations that would lend themselves to this kind of solution? If indeed this would have been a solution, why wasn't it tried?

Perhaps the National Park Service has found the unique solution to the problem of vandalism. We have at El Morro National Monument an entire area set aside to preserve vandalism. We call this particular vandalism "history," however. Incised upon a rocky bluff at El Morro are the names and

sentiments of many of the early explorers of the Southwest, dating back to Don Onates in 1605. Additional "vandalism" is not wanted at El Morro or as Freeman Tilden[2] in his book The National Parks puts it:

> No further names, addresses, or telephone numbers, either on El Morro or on any other natural or manmade feature in the National Park System, are desired. This may seem odd to today's aspirants for immortality. They must remember that they are not Don Onates, and the year is not 1605. Requirements and values shift with the years.

The values of some people have not changed, however, and therein may be the solution of the problem of vandalism. We need to find a way to bring the values of some of our visitors up to date. Maybe we can do it by talking to them, or by strict enforcement or by...what?

I don't know the answer, but I do know we can't afford to wait 200 years so we can call vandalism history.

[2] Tilden, Freeman. 1951. The national parks: What they mean to you and me. 417 p. Alfred Knopf, New York.

Vandalism in California State Parks

Thomas Miller[1]

The dictionary defines vandalism as "the willful destruction or defacement of artistic works, or property in general." A few examples of vandalism are defaced signs, broken windows, wall panels kicked out of restrooms, graffiti painted on walls, wooden structures destroyed or used for firewood, historic artifacts painted or mutilated, and vehicles damaged. The list can go on and on. The purpose behind the act of vandalism is often difficult to recognize. I will explore some motives later on in this paper.

To get to the whys of vandalism, let's look at who the vandals are. "Kids--you better believe it! The kids are knocking us apart." True? Not necessarily. "It's the ethnic groups from downtown, that bunch of people that ca even speak English, they are the ones that do the damage." That statement isn't any more true than the one about the kids. The fact is we can't pin the tag of vandals on any particular segment of the population. As an example, I have witnessed people from the "establishment" (you remember that term--over 30, live in a house they are buying, etc.) doing things that resulted in the defacement or destruction of property--property that was not their own--public property. That meets the definition of VANDALISM.

I specifically recall a man of about 30, cutting his initials into a tree. The tree, by the way, was so scribed with initials that it was dying from the cuts, just as though someone had girdled the trunk. The man was willfully destroying the tree, an act of vandalism. Upon my questioning, he told me in no uncertain terms that he was not doing anything wrong! This is an illustration of part of our problem. Many vandals may not even recognize that they are vandals.

Who then are the vandals? We may all be vandals at one time or another, depending on our impact upon the property around us as we go through our daily routine. If what we do results in damage or destruction of property, we have vandalized. What about the willful part? Vandalism is work: some acts take more energy than most people are willing to expend while earning wages on their jobs. They aren't being paid to vandalize--what they do is voluntary and willful.

Who are the vandals? Anyone who is strong enough and old enough to do something that defaces or destroys the property of others. That's most of us. When many people are capable of being vandals, it's no wonder that vandalism is a big problem. Because vandalism is an act that results in the destruction of property, and almost everyone is capable of committing an act of vandalism, the big question is why?

Some experts have demonstrated that vandalism results from the need for recognition. Good results in reducing vandalism have been

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achieved at Grape Elementary School in Watts through a program designed to provide positive recognition for all of the students. This is an approach beyond my ability to explore and develop. I am hopeful the psychologists will continue working along these lines and eventually suggest ways to provide for the individual's need for recognition.

Some causes of vandalism are less clearly connected with the need for recognition. Selfishness is high on the list. Selfish acts often occur in the quest for firewood. The act of vandalism includes reducing items to a size that will fit in the fire. Anything made of wood is the target, and signs, posts, doors, food locker shelves, and wall panels are examples. The trees and undergrowth in the camping areas are also sacrificed in the quest for fuel.

Another example of the selfish motive for vandalism can be observed in areas of historic interest. Photographers have been known to paint over pictographs so they will provide enough contrast to show against rock backgrounds. Historic pictographs have been destroyed through such acts of vandalism. Unauthorized digging in archeological sites destroys the story of events. Artifacts, once removed, become only conversation pieces in the hands of untrained people who have selfishly deprived others of enjoyment.

Retaliation is another reason behind vandalism. Acts of retaliation are typically those that happen in the dark of night. The lifeguard tower that was chopped down and the building with all of the windows knocked out are examples. It is the vandalism of retaliation that we in the field can do the most about. It represents our public image barometer. If we have a significant amount of retaliatory vandalism we have a significant public image problem. How can you tell if the vandalism was retaliatory? It is not difficult; take a look at what your organization did yesterday. It is amazing how the vandalism correlates with arrests or other enforcement acts. For example, in one area we know that all of the windows would be broken out of our entrance stations whenever enforcement action was taken against a local group. I'm not proposing that we turn away from controlling the negative actions of visitors with the result that one group infringes on the rights of others. I am saying that if vandalism is the result of a lack of respect, then to lose the respect of visitors will increase the vandalism rate; the opposite is of course true--gain the respect of visitors and reduce vandalism problems. To focus on vandalism is to focus on the relationship between the users and the agency that manages the land.

What does vandalism cost? It is not easy to put a dollar value on it. We know that in one area the cost to repair damage caused by vandals was $2,330 during the summer of 1975. That figure does not truly represent the costs of vandalism because the loss of availability of the facilities to other people cannot be calculated. Neither can the permanent loss of resources such as trees, understory brush, soil, or historic artifacts be represented by a dollar amount.

The costs of vandalism are going up every day, along with the increased desire of the public to utilize public property. The costs are too high for us to chalk up as the expected cost of providing for public need. We have a responsibility to attempt to reduce the cost by attempting to reduce the rate of vandalism.

Vandalism in a City Park

Richard Sampl[1]

A great deal of so-called vandalism is caused by accident and is not really vandalism at all. The term "vandalism" is a marvelous catchall for public apathy, ignorance, lack of concern and/or intellectual laziness.

In Placentia, the only vandals are the designers, specifiers, and installers who provide the opportunity for the so-called vandalism to occur, and over the years I must include myself as one of these. Seventy-five percent of what is labeled "vandalism" in the city of Placentia could be prevented through design. The remaining 25 percent is malicious and unaccountable.

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[1] Director of Recreation and Maintenance, City of Placentia, California.

We feel that vandalism is an attitude and is controllable for the most part. Our records show that the wanton and malicious destruction is often done by groups, usually young males in the 14 to 16 age group. We have also noted that this age group holds the largest number of school dropouts and others who enter the mainstream of adult life unprepared to act according to adult rules, and too young to be given the status that would go with compliance.

Destruction in the expression of a need, and an interpretive look at the motivations behind these kinds of vandalism may open the door to innovative solutions. I have taken the liberty of classifying vandalism in the city of Placentia in six categories[2]. I would like to share these with you:

1. Vandalism of overuse--This type of vandalism can take many forms. You can swing only so many times until the chain wears out. How many kids can sit on a bench? How many balls can go through a hoop? And the merry-go-round has only so many turns.

2. Conflict vandalism--This is the reaction to a tot lot built in the middle of a baseball field, a concrete climber built on the basketball court, a fence where a gate should be, and grass where kids want to walk. It is the expression of kids doing what is logical and most natural and/or most appropriate to them regardless of the designer's intent. It may be a tree planted where kids want to play ball or it may be the perfect place to use for second base or to swing on the way to third--a tree breaks and "vandals" are blamed. Vandalism may be the tree branch too low to walk under, too long to walk around, or just the right height to swing on.

3. Leverage vandalism--This usually prevails during baseball season. It's finding a hole or a slot just the right size to pry with a baseball bat. The bat is stuck in a hole, the board is pried loose from the bench, the loose board is then carried to the jungle gym, where it is propped on the bars to form a cantilever. It is the concrete trash can which couldn't possibly be stolen, but of course, it also can't be emptied because it weighs too much, especially after the removable steel liner has been carried away. If it doesn't work as a trash can, maybe it can be used as a battering ram.

4. Curiosity vandalism--This is the answer to what is behind the locked door or behind the sprinkler controller or under the manhole cover. It is the act of jamming a stick in th drinking fountain to see how high the water wi squirt, plugging a drain to see how high the water will rise, pulling up a tree to see what the roots look like, and taking apart the playground climber to check the construction.

5. Irresistible temptation vandalism--This is writing on a shiny painted surface wit a magic marker or riding a bicycle through the big mud puddle in the new lawn where the drainage is improper. It is climbing out on a tree branch to see how far it will bend or throwing a bottle against a concrete wall. It is picking flowers or unscrewing the beautiful brass thing on top of the fountain because it fits sc nicely in the palm of one's hand.

6. The no-other-way-to-do-it vandalism--This is why the bicycle is leaned up against th tree when there is no bicycle rack. It is thro ing papers and bottles on the ground when there is no trash can and using the sand box when the is no restroom or when, worse yet, the restroom is locked. It is sitting on the fence and hang ing your jacket on a tree.

During the years, we have found that many administrators, faced with finding solutions tc vandalism, expressed their reaction in two classic attitudes. The "bastille" approach is building something so strong, so massive, and so simple that kids couldn't possibly tear it down. It's just to make sure, erecting a high fence so the kids can play only when administrators let them, and if the equipment still gets broken, locking the gates.

The "zero" approach provides nothing, therefore there is nothing to break. Put up a fence with no gates, pave the area but don't plant trees or grass.

We in Placentia feel the only solution is a creative approach. It is to try to understar a child in search of diversion after school, tc anticipate the alternatives and opportunities open for overuse, conflicting uses, or misuse of playground environments.

Possible solutions for some of the varieties of vandalism which I have spoken about include:

1. Provide sufficient equipment to discourage overuse

2. Build a path where the kids walk, provide a gate next the hole in the fence. Plant more trees and provide a way to run through the flower beds so kids and plants can grow togethe

3. Unlock the gates or remove them so they won't be torn down, prevent the gate from becoming a swing

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[2] V. Michael Weinmayer. 1973. Vandalism by Design, A Critique. In Reflections in the recreation and park movement. David Gray, ed. Wm. C. Brown Company.

4. Check and remove loose boards and stray items used as levers and hammers

5. Mount trash cans on poles, replace when damaged and empty when full

6. Use timbers, difficult to write on, but can accommodate graffiti, and they mellow with age

7. Bicycles should have racks and people should have benches

8. Install wrought iron fences to control cross circulation. This use will help stop kids from running into the street but will not cause problems by catching windblown debris

Vandalism in Placentia has been a problem. We do not have the answers. The thing that we have learned the hard way is that there is no such thing as a maintenance-free park--maintainable, yes, but not maintenance-free. We have environmental impact reports. Every development contemplated should also have a maintenance impact report that identifies areas and items which require maintenance and will cost money over the years. Parks need care every day, improvements every year, and major rehabilitation about every 5 years. Kids in Placentia do not destroy what they want, like, and use.

Vandalism in Organized Camps in California

Patrick C. Dickson[1]

The American Camping Association in California represents approximately 500 member agency camps, private independent camps, and church-affiliated camps. Annually the Association provides organized camping opportunities for approximately 1.2 million young Californians and an additional 500,000 adults use member facilities during the off season.

During the past three years, according to insurance carriers, dollar losses due to vandalism have been minimal, with less than 1 percent of the total membership reporting substantial dollar losses. This trend appears to be consistent even with increasing exposure due to increasing enrollments and programs utilizing facilities on a year-round basis. The major problem facing camp operators is coping with vandalism appearing in two forms: (1) External Forces: vandalism done during nonscheduled times by "outsiders" and (2) Internal Forces: abuse of facilities during organized programs.

The member camps of the American Camping Association have minimized dollar losses due to vandalism by subscribing to rigid accreditation standards which require sound site planning and sound administrative procedures in the organized camp and camping program. Furthermore, a high percentage of member camps have engaged fulltime onsite caretakers to patrol and act as a deterrent to possible threat from external vandals. Internally, member camps have instituted ongoing educational programs for the participants, emphasizing and providing opportunities and experiences for developing awareness and appreciation of the interdependence of all living and nonliving resources and a sense of responsibility for them.

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LAW ENFORCEMENT

Photo: East Bay Regional Park District

Vandalism and Law Enforcement on National Forest Lands

Thomas A. Hoots[1]

Vandalism on National Forest lands, as well as on other land in both public and private ownership, is relatively new. The campgrounds and facilities on Forest land have been open to the public on a self-service basis as long as the Forests have been in existence. Up until the mid-1960's, a camper could leave equipment and food readily visible to any passersby without fear of loss. Signs could be erected in campgrounds with full knowledge that those signs would remain in good condition until such time as the weather might fade the colors. The worst vandalism that occurred in the National Forests was caused by bears. I can recall sitting in meetings similar to this one, trying to figure out what we could do to minimize bear damage. Bears are still around, but we certainly don't spend much time talking about the vandalism or difficulties they create.

The current problems are people, not all people, but just a very small minority of people who have created a condition among the National Forests that is causing great concern.

Who are these people? What has changed that makes it all right to destroy $336,000 worth of improvements in the four southern California Forests? What right have these people to deprive the general public of 26,000 visits to a National forest to enjoy a camping experience? Yes--facilities for 26,000 visits could have been built and maintained with the dollars spent in replacing damaged and destroyed improvements. What cost can be placed on painted rocks and carved or chopped trees?

A change has occurred since the 1950's. During the 1960's, a new generation discovered the great out-of-doors and with it the National Forests. Their culture developed in the cities and was foreign to the parks and forest. It was marked by laziness, softness, and disrespect. President Kennedy identified the problem to some extent and encouraged physical fitness programs. There is much discussion now about the apparent destruction caused by the timber industry. I often wonder how it compares with that in recreation areas caused by the tremendous increase in use we have recently experienced.

We know some things about these new user groups. We know that they are young and city oriented. We know many lack the know-how or awareness of how to treat nature. We see an increase of users from cultures other than Anglos and from low-income groups. We see people who have been sold on an outdoor experience by salesmanship for new products for use in the open.

From 1968 to 1973, I was a District Ranger at Pinecrest on the Stanislaus National Forest. It is about 50 miles north of Yosemite National Park, and is part of one of the most heavily used of the National Forests. During this time, the changes in user groups became clear. Probably the most spectacular evidence came in Yosemite Park where Park Rangers on horseback confronted hundreds of "hippies" in a meadow. The results, besides many arrests, were injuries, a dead horse, and a destroyed meadow. What caused the confrontation with baton-swinging Rangers? The unlawful use of the meadow for a camping spot. Sounds silly? To the hippies, the right to camp there was worth fighting for, and to the Rangers, keeping the campers out of there was necessary to support the principle the parks were established for--the protection and preservation of a unique national heritage.

At Pinecrest, we were faced with similar problems, but were fortunate in being able to see and learn from the Park's problems. We saw riots, numerous arrests, and destruction of property. We made some studies of these problems, which include 109 incidents of vandalism in 1970 alone. We found that 62 percent of the incidents were caused by people under 21 years old. Also, we found that vandalism and thefts occurred between the hours of 10 and 11 A.M., 2 to 4 P.M., and 8 to 11 P.M. These included only the incidents for which we had enough information to make a record. Conditions have changed, but vandalism is still here and even increasing. The new user groups are also still

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ıere, though not as easy to identify.

On the San Bernardino National Forest, we ıre finding that vandalism problems are occur-·ing more frequently during periods of low use, ›n weekends, and during the off-season, when :he facilities are untended. We also see ıigher vandalism occurring in areas more ıeavily used by low-income groups, and in areas ıithin 30 minutes of valley communities.

A prime example of this type of vandalism ›ccurred last month in a campground about an ıour from the San Bernardino Valley. The camp-round was completely rebuilt last fall in a ooperative venture of the Southern California ıssociation of Four-Wheel-Drive Clubs. The ampground is along a dirt road and was then overed with about 6 inches of snow. About hree groups of young people were camped there, ost of them teenagers with no adult supervi-ion. Someone had sawn the wooden barrier ails into firewood sizes and had also taken a able top apart and sawn it up. There was resh evidence of sawdust in the snow. At all hree campsites, burnt or burning parts of the arriers and tables were in the fireplaces. hen we questioned members of the groups, natu-ally all of them denied any knowledge of how he wood was cut. They said they found it ly-ng there, cut up. From a law enforcement tandpoint, even though circumstantial evidence trongly indicated that someone in those camps as responsible for the destruction of the ails, barriers, and table tops, we could do othing.

To keep campgrounds open, in such a situa-ion, means having caretakers present to assure ıe protection of the facilities. Unfortunate-y, it is costly to put caretakers in camp-rounds with minimum use. It is almost im-ossible to effectively close off the camp-rounds, because this would require closing any of the main roads and highways within the orest.

A strong, tough law enforcement program is ›eded to minimize the vandalism problem as ›ll as to provide some feeling of security for ıe recreationist. We need to be cautious, ›wever, that we do not penalize the honest ›er by presenting him with complicated or re-:rictive requirements that destroy his exper-›nce. The average person won't mind some in-›nvenience if he knows it will provide him th security for his family and protection ıainst theft.

One trap which recreation managers must oid is becoming "cops" and forgetting the ime purpose of their jobs. In other words, 'hen you are up to your waist in alligators it easy to forget your objective was to drain e swamp." Speaking from experience, I found myself in 1969 and 1970 chasing pot users and minors with alcoholic beverages, and dealing with nudity problems and even grand theft, rape, suicide, and murder. There was a fine line between problems associated with the recreation users and their experience and just plain law enforcement problems. I had to cross that line before I recognized where it was.

As we examine vandalism on National Forest lands, we tend to concentrate on the large developed facilities. An area of increasing importance and increasing use which is often overlooked is backcountry. When speaking of backcountry, we frequently think of wilderness, but I am referring to any minimum-development area. This means road- or trail-access areas primarily but could be any area. Here vandalism is really a serious problem. There is virtually no way to stop the destructive force. Fortunately, those who are bent on destruction do not visit these areas frequently unless there are roads. The signs certainly reflect this.

Some of the improvements vandalized are pit-type toilets, signs (great targets for the marksman), nature trails and water developments. The beauty of the forest itself is also destroyed. How can these areas be protected? Now, when they are destroyed, we frequently remove the improvements. In one campground where a replacement toilet was shot up within 6 months, and the tables were stolen, cut up, or burned, we just closed the area. Hundreds of visitor days of public use were lost. The public is paying for the vandalism in more than dollars. How can we measure the loss in vegetation caused by cutting down, carving or chopping trees, or by the worst of enemies--fire? The $336,000, previously mentioned, does not begin to measure the various types of monetary, esthetic, and emotional losses.

IDENTIFYING THE PROBLEM

We have discussed the evidence. Now what has been or can be done? Many methods have proven successful for individual problems and many more have proven unsuccessful. Before looking at some individual solutions, we should first learn the components of the problem. All instances of vandalism are not the same. We should start asking questions:

1. What was the result of the action--what was damaged or destroyed?

2. Who is causing the problem--what is the age group of users, where do they come from?

3. When does the problem occur--night time, weekdays, off season? Can a time of day

be identified?

4. Why does it occur? Disrespect, anger, frustration, boredom?

5. Are the facilities designed to minimize vandalism?

Some of these questions may be easily answered, but what about the more difficult ones? I am a believer in public involvement. Public involvement may be time consuming and may not answer all of our questions, but I feel it is our most promising opportunity to find answers. Go to the user groups and rap with them about what's going on. Spend some time with the groups who are suspected of creating most of the difficulties. Listen to their suggestions. Understand what is important to them. Learn their values. Seek the cooperation of the users not only in studying the problems but in repairing some of the damage or in designing new protective devices.

Consider the cultural differences between user groups and their relation to facility design. The most outstanding difference I am aware of is in the typical family unit design. Almost 100 percent of the San Bernardino Forest campgrounds are designed as single family units, capable of serving 5 to 8 persons at one time. The Mexican-American family typically consists of the immediate family, the relatives, and a few friends, and can include 3 to 5 vehicles and 10 to 20 people. What happens when they arrive? They all must crowd into the family unit, which means removing the barrier or driving over it. The large numbers of people can't help but trample the vegetation. The campground becomes crowded, ruining the experiences of others, and the facilities are overused for their design. When the Ranger arrives, he hassles the group for having too many people and for the mis-parked vehicles; he either asks them to move or writes them a citation. The group gets mad and stops caring for the facility. They may leave, but they leave behind litter and broken facilities, and everyone has had an unhappy experience.

Is this sequence of events necessary? It occurs because we are not providing a design to meet the needs of all the using public, with a result frequently classified as vandalism.

Clear, concise signing is part of the same problem. Where are the bilingual signs? In southern California, recognizing the different needs of different cultures, especially the needs of the Spanish-speaking peoples, is a must.

FINDING SOLUTIONS

The various techniques for reducing vandalism can be classified in three basic categories: public assistance, direct control, and engineering.

Public Assistance

A public assistance program tends to increase the user's enjoyment of the area by providing a feeling of security and increasing user understanding of facilities, activities, and the environment.

Providing maps and brochures is probably the first step in this process and has been used at many areas for a long time. These should be printed bilingually where non-English speaking cultures compose a significant part of the user group. People inexperienced in the use of English misinterpret statements even though they can read the words.

Signs, preferably symbol signs, certainly aid in minimizing confusion and lowering frustration levels. Where signing may be difficult or expensive, the use of radios with limited range transmission which can be received on automobile radios can help. Again, use bilingual messages.

Information specialists, who are bilingual where appropriate, can provide some personal touch and promote facility security by their presence. In lieu of manned stations, well-designed and displayed bulletin boards and kiosks provide opportunities for expanding the user's knowledge.

At Pinecrest, we developed positions called Public Assistance Officers. These recreation aids were given public contact training information on questions commonly asked, first aid training, and law enforcement training. Their job was to work with the public and to take a firm hand when and where necessary. They had direct contact with the resident deputy sheriff through special radios. These persons enabled us to achieve successful control of a difficult situation principally because they took the time to talk to the users.

Another program which helped was "Pack-in, Pack-out" which was used in the backcountry. Personal plastic garbage bags were provided, with the rules imprinted in a colorful and artistic manner. These bags eliminated a large amount of litter and allowed 15 to 20 garbage cans to be removed. Previously, many of the cans had to be replaced annually because they

were shot, stolen, or otherwise destroyed. Contests proved successful among the younger people. One which has been going on for 3 years is the pop-top chain. The person with the longest chain gets a Smokey Bear patch.

Direct Controls

Direct controls are those which impose some form of control over the user. These are frequently effective but they also tend to destroy the designed recreation experience if not done cautiously and with some thought.

Perhaps the most popular control is the entrance station. The National Park Service has been using this form of control for many years. Entrance stations do not have to be elaborate. I once used an old out-house, repainted and slightly redesigned. In some areas, gates which are closed at 10 P.M. have been used; these prohibit the entrance of people who are not actually camping on the site.

The San Bernardino, as well as other National Forests, is using permanent caretakers in the campground. These caretakers usually occupy the first camp unit, and live in a trailer which remains for the season. They collect fees, process reservations, do some facility cleanup, and provide security. The Inyo Forest is presently seeking volunteers, from among the retired senior citizens, to fill these positions. As volunteers, the caretakers receive a uniform, some training, and expense money but no wages. They sometimes work in sites also controlled by entrance stations.

User permits, such as those issued for wilderness areas, provide a certain psychological control because the agency has the user's name and address and the user is given a specified time to use the area. He is even directed to the exact spot he is permitted to use.

Engineering

Engineering includes the design and construction of facilities. Design plays a major role. It includes the basic campground layout (camp loops, size of units, location of signs, garbage cans, restrooms, and entrance stations) as well as the actual design of a given facility. For example, in isolated locations, rocks or cement barriers may be used in lieu of easily destroyed wooden barriers and rails. In one camp, we have resorted to concrete bunkers for restrooms because the standard ones were repeatedly destroyed. These are certainly not meeting our visual quality objectives, but the toilets are available and are only being painted with names and some choice phrases, rather than being destroyed. Our engineers and landscape architects play a valuable role in design, but they must also understand the objectives of a recreation experience.

SUMMARY

The vandalism problem is definitely a difficult one to solve. I think each Unit Manager has to examine his own problems and his own users, seek public involvement, and develop solutions that are adapted to the particular area. Through this symposium, each of us will acquire a so-called "bag of tricks," from which we can select the one that applies to our particular area. Through concerted effort and working with the user, I think that we can reduce the vandalism incidents. For me, however, law enforcement, the "cop" approach, is our least desirable alternative. Prevention, through user involvement, should be our first aim.

Vandalism: The California State Park Approach

Jerry Morrison[1]

The California Department of Parks and Recreation has a history of setting an example of how to approach criminal incidents, including vandalism. In 1968, the Legislature, through the California Peace Officers Standards and Training Commission, requested a study of crime in State parks. On the study group's recommendation, six people were hired for the six districts of our Department. These people were chosen for their expertise in police service, and their anticipated approach to the incidence of offenses within the parks. I'm one of the six; my area is District 5, which extends from Santa Barbara County to Orange County and from the ocean east to the Arizona-California line. I deal with two dozen law enforcement agencies within those boundaries.

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[1] Law Enforcement and Safety Officer, State of California, Department of Parks and Recreation, Goleta, California.

The six people chosen for this special duty began almost immediately to improve the training of the Rangers in approaching law enforcement situations. This training has been continued and enhanced; the Rangers now receive the full amount recommended for policemen at our academy in Monterey. Many carry weapons in their daily routine, not by choice, but because is has been found necessary. We recommend a soft approach to law enforcement; however, a firm one. We recommend high visibility. We want the Rangers to be seen, but we do not want them to be oppressive. We want them to approach problems before they develop, if possible, and to talk with the people to try to establish a relationship with them, try to establish some understanding by them of why we have our rules, and try to educate them about what these rules are.

We are here concerned with the explicit act of vandalism. Vandalism is defined as wanton destruction; it is a criminal offense. Again, it is an offense of negligence as often as not--like not stopping at a stop sign in a traffic situation. It can be an offense of ignorance, like not stopping for a red light because one is color blind. It can be vindictiveness towards what has occurred in that place or maybe a reaction against a symbol of authority or the system. It can be a social thing, a need for recognition for a culture or an individual personality, such as drawing a symbol on the restroom--a symbol that identifies the individual and his personality. This is not really an endeavor to damage, not an intention to hurt, but an act of seeking identification. Therefore, we find that vandalism can be negligence, ignorance, vindictiveness, or self-expression or all of these.

We are also concerned with the dimensions of the problem and how to measure it. We have to guess. We can guess on the basis of data, but this is faulty, and I can explain why. The most recent FBI Uniform Crime Report was for the year 1974. It stated that 7000 arrests for vandalism in rural areas in this country were reported during that year. However, vandalism arrests are not easy to make. For each arrest there are many, many offenses that are commited by persons unknown. Data provided by the Federal Bureau of Investigation shows that the age of persons arrested for vandalism ranges from very young to quite old, and there is a significantly large group between the ages of 13 and 14 years. Attempts are made to measure vandalism by the amount of money we spend for repair. My department budgets $50,000 per year; however, we had $87,000 damage reported in 1975. I would say that a minimum of double that amount is the true figure: we probably suffer over $180,000 vandalism damage per year in our department. I base this on the fact that no one likes to make reports. In our system, there is one crime report to be made on the vandalism itself and another to recover the money for the damage. Many of our people say, "Oh, fix it and forget it," rather than take the time to make the reports. In other places, some may say in effect, "As long as we don't report problems, people will think we have it under control and we'll build a great reputation." A great reputation--yes--but things are getting ripped off; it's like the sea eating away at a cliff until a shoreline house falls in the drink, and then it's too late.

What do we do about vandalism? What action do we take? I must admit that I have committed an act in a Federal forest that could be construed as vandalism. I moved a rock so that I could park my camper in a location that I deemed better. The regular parking place was in bright, hot sun. The rock was preventing me from moving to where it was shady, so I moved the rock and parked in the shade. My point is that the campsite should have been designed to take the campers needs into account. It is not enough to simply set rocks around and say to the camper, "Park there." Good design would see to it, for example, that people going to a day use area don't go through a campground to get there. Why not? Because after they have been there, enjoyed their picnic, and drunk a few beers, if they must leave through the campground, and if there is something there that is not being guarded, they can just pick it up. Furthermore, they find a handy place to throw away their beer cans as they pass through.

We should have our people in the use area, where they can be seen and can be talked to when visitors are there. Make guards or caretakers visible. Have them talk to the people before trouble begins. Help them to understand what the rules are, and why they are needed.

In summing up, I believe a wide selection of disciplines are needed to uncover solutions to the vandalism problem. Hopefully, we can identify some new approaches, some actions that will help us in this exercise in waste.

Vandalism at Red Rock

John C. Einolander[1]

Vandalism calls are an everyday xperience for a law enforcement officer. sually acts of vandalism are perpetrated y juveniles. Vandalism, along with all. ther crimes, is on the increase. Last ear, the largest rise in crime was in the ural areas, where we saw an increase of 1 percent. Vandalism is not new to our odern society. It has been a problem in ur cities and towns for centuries. The erm vandalism is derived from Vandals, a ermanic people who sacked Rome in 455 A.D. ne legal definition of vandalism is "willul or malicious destruction, injury, disigurement, or defacement of property withut consent of the owner or person having ustody or control." This crime is classfied as a misdemeanor, and is punishable y a fine, a short term in jail, or both.

Vandals can strike at any location. owever, their favorite targets have been ity schools and parks. In the past 10 ears, the monetary loss from acts of vanalism has risen to 3 to 4 billion dollars year. As every victim and every law nforcement officer knows, it is often exremely difficult to apprehend vandals. any cities have devised innovative ethods to prevent and detect vandalism, nly to find that methods to circumvent etection are quickly devised in turn. xpensive electronic sensors and closedircuit television systems have been nstalled, but with only marginal success n many areas. As an experiment, Washingon, D.C. installed $365,000 worth of odium vapor lighting equipment in certain reas. They were rewarded with a 22 perent reduction in vandalism. Washington as greatly increased the area covered y their sodium vapor lighting program. his is apparently one method that has et with success.

Although vandalism is not at all ew to the cities of our United States, t has become a new and ever-increasing problem in the National Forests and Parks. In the Santa Barbara District of the Los Padres National Forest, there is an area known nationally among young people as "Red Rock." This canyon area has a 10-mile winding stretch of two lane rough road along the Santa Ynez River. The river is surrounded by rugged mountains, and entry to much of the area is restricted during the summer months because of the extreme fire danger. The official name of the area is "The Lower Santa Ynez Recreational District." There are ten campgrounds, of which three are for daytime use only, and seven are for overnight use. The area is designed to accommodate approximately 4000 persons for recreational day use, and a maximum of only 1500 for overnight camping. Over the last 6 years, in this small area, both day and overnight use has increased phenomenally. On heavy-use weekends during the summer months over the past few years, as many as 15,000 people entered the canyon on a single day. The crowds heavily overloaded the facilities and the reasonable capability of the terrain to support use. Along with the increased use came a large rise in city-type problems, and city-type crime--traffic congestion, family fights, drunkenness, narcotics use, shootings, thefts, robbery, and assault, along with litter pollution, and a tragic upsurge in vandalism.

Here are only a few examples of what has occurred in the small recreation area of "Red Rock":

Spray painting of cliffs, rocks, toilets, signs, trees, and tables with obscene words or person's names

Chopping down of trees, shrubbery, and signs

Mutilation of buildings, toilet facilities, water pipes and water systems, camp tables, stoves, and anything else that can be destroyed

Destruction of vegetation by driving motorcycles and other vehicles through the campsites and across the natural countryside and spinning the wheels or sliding sidewise (commonly known in city lingo as "yard farming")

Sergeant, County of Santa Barbara, heriff's Department, Santa Barbara, alifornia

Shooting of holes in buildings, toilets, tables, trash bins, and trees

Burning of anything in sight that can be chopped down and burned, including camp tables and other facilities

In those we have apprehended for acts of vandalism, we have seen a strange, don't-give-a-damn attitude. One group was caught in the act of burning their camp table in the camp stove, piece by piece. Their comment was "It wasn't worth much anyway." One man, chopping down a live tree, states, "Well, how else can I get my camper backed next to the camp table?" A 28-year-old, who had blocked the road by rolling large rocks across it, said, "It's too damned crowded, and I wanted to keep some of those nuts out of here." Two men who were arrested for shooting into an occupied toilet facility stated, "Aw! We were just having a little fun. He didn't get hurt." On a dark, moonless night, in a crowded campground, one fellow fired 40 rounds from his 30.06 rifle in random directions. He claimed that he had heard ominous rustling in the surrounding bushes, and he thought somebody was going to get him.

In order to help maintain the peace, and to preserve the facilities in the Lower Santa Ynez Recreational District, the Forest Service contracted with the Santa Barbara County Sheriff's Department to assist them. Sheriff's Deputies began working weekends during the summer months of 1970. This first summer, one full-time Deputy and several reserve officers patrolled throughout the area. The recreational population increased, and the crime increased to a point that in 1975 it was necessary to have as many as twelve Deputies patrolling on the weekends just to maintain an acceptable level of order. It also became necessary to maintain two to four full-time patrolmen throughout the winter months because of the increase in mountain area use.

I said that as many as twelve Deputies were required to maintain an acceptable level of order. We were unable to stem the acts of vandalism. In the summer of 1974, the Santa Ynez Campground, which provides nice, wide-open tree-covered campsites with toilet facilities, camp tables, stoves, and running water, was damaged to the point that it had to be closed.

In 1975, summer campers destroyed the Red Rock Campground, and it was closed. In both these camps, toilets were smashed, tables were burned for firewood, and steel stoves were cut from their 2 1/2-inch pipe mounts and stolen. Trash cans were run over or shot up, and some were also stolen. Trees were chopped down, and rock and wood camp barriers were driven over, moved, and mutilated. Grim? You bet it's grim! The Forest Service estimated that during the year, in this small area alone, there was $25,000 damage to the recreational facilities.

Campsites are expensive, material and ma hours for repair or rebuilding are expensive, and patrol time for law enforcement is expensive. Is there an answer on how to solve thi wanton destruction of property? I don't know the answer. We seem to be losing the battle.

Of the methods used in the Red Rock are to try to stem this type of vandalism, some have proved to be fairly successful:

Sheriff's Deputies and Forest patrolmen in uniform, driving marked vehicles, patrol the campsites at random times throughout the day and night hours

Sheriff's Deputies on foot, in uniform, walk through the camps during the day and nig hours at unscheduled times

Deputies on horseback and on foot patro the river banks and out-of-the-way spots wher campers congregate (horseback patrol appeared to be a good psychological deterrent to acts of vandalism)

Problem areas were staked out with came equipment, to take photos of vandals in actio so as to apprehend them

The Forest established a temporary chec station at the entrance to the canyon. Each car was stopped, its license number recorded, and the driver provided with a copy of the Fe eral camp regulations

The Forest tried camp sitters who lived rent-free, in trailers, and reported any suspicious activity

Enforcement of the rules and regulation both State and Federal, was used as a method of prevention. Sheriff's Deputies issued approximately 1200 citations, arrested 350 people, wrote 800 crime reports, and issued thousands of verbal warnings

It is very clear that vandalism is a bi problem in the National Forest. I see no end in sight. The projections state that an approximate 15 percent increase in use of the National Forest lands will occur each year. This means more vandalism. At the rate we ar seeing the camp areas destroyed, we may face limiting camp use to a select few, or closing campgrounds during certain periods.

A solution to the vandalism epidemic mus be found. Otherwise, it will soon mushroom to such outrageous proportions that outdoor activities and camping in our National Forests will be only a memory.

Law Enforcement and Vandalism in Our National Parks

Nicholas Whelan[1]

National Parks were established in the United States in 1872, with Yellowstone our country's first public pleasuring ground. From that time on, areas of the National Park System have been bothered to a greater or lesser degree by problems of vandalism. Our first visitors shot Yellowstone's wildlife, cut trees, marked up or tore down geyser formations, and in general acted in an irresponsible and short-sighted manner.

Initially we were absolutely powerless to stop any of these actions because we had no people in charge and no laws (a common complaint among many agencies even these days). If a Park was lucky, it had a superintendent, assuming someone could be found who would work for nothing, because that was the pay for the job. If a violator was actually caught doing something seriously wrong, the only power the superintendent had was to put the person out of the Park. The problems became so overwhelming that in 1886 the Secretary of the Interior asked the Secretary of War for help; for the next 30 years the army controlled the Parks--not an ideal solution, but at least during that time these areas were protected.

In 1894 Congress passed the first protective law for the Parks, an "Act to Protect the Birds and Animals in Yellowstone National Park," and in 1906 the Antiquities Act was passed to protect archeological sites; both of these gave the Parks laws pertaining to the protection of specific features.

It was not until 1916, however, that the National Park Service was established, and the enabling act also gave us a general idea, finally, about what the Park Service was supposed to consider important, nicely summed up in these few words, "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for future generations."

Now we have about 300 areas and almost 2000 permanent rangers; we were visited by millions of persons last year, and investigated thousands of cases of vandalism. Our National Park Service rangers are authorized by Title 18 of the U.S. Code to be Federal Law Enforcement Officers, and the laws pertaining specifically to National Park Service areas are contained in Title 36 of the Code of Federal Regulations (naturally, these are all misdemeanor offenses). Our role, in other words, is much better defined than it was during those first few years at Yellowstone and Sequoia. Nevertheless, National Park Service law enforcement remains a bit enigmatic to many outside of the service because it is not absolutely structured and contains several variables.

For instance, our Park areas may be governed by any one of three different kinds of jurisdiction. Some Parks have "exclusive" jurisdiction, whereby Federal law is the only law and Federal officers the only law officers. Most older Parks have this type of jurisdiction (or a slight variation of it). Most of these Parks were established before the States they are in were admitted, so it's easy to see how this type of jurisdiction developed.

A second and quite common type is "concurrent" jurisdiction, in which the Parks are governed by Federal laws (not just the Code 8 Federal Regulations but also the U.S. Code) and by State laws equally, and both Federal and State officers can enforce them. Parks which have this type of jurisdiction fall under

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[1] Park Ranger, Channel Islands National Monument, National Park Service, U.S. Department of the Interior, Ventura, California

the Assimilative Crimes Act, which means that laws other than Federal laws within that particular political area are automatically assimilated into the laws of that Park.

Channel Islands National Monument has the third type of jurisdiction, "proprietary," which is in many instances the least desirable of the three from the viewpoint of the Federal officer in the field. Under this type of jurisdiction, the Park Service has no more power than the owner or proprietor of any other piece of land. We may, as proprietors, modify State laws to make them more restrictive, but we may not make them less so. The one concession we have to the fact that our role differs slightly from that of other landowners is that we may levy legal punishments when our rules are broken. Within our rules, Title 36 of the Code of Federal Regulations, there are sections which enable the Parks to assimilate State fishing and motor vehicle laws and U.S. Coast Guard boating regulations. This leaves quite a few laws --for instance, any State felony laws-- which Park Rangers may not act upon with any more authority than that of a private citizen. To rectify this situation, many rangers in Parks with proprietary jurisdiction arrange to have themselves deputized by the local sheriff.

To return to the problem of vandalism --this is covered under various sections of Title 36 of the Code of Federal Regulations and is handled by a citation if this appears warranted. The citation, a National Park Service form, can specify that the violator either appear in court or not; if the citation does not specify that the violator appear, he still has the right to do so, or he may simply mail in the bail forfeiture. This bail is sent, in our case at Channel Islands National Monument, to the Central Violations Bureau of the U.S. District Court in Los Angeles. If a violator wishes a hearing, however, he is directed to the nearest U.S. magistrate. In most of our vandalism cases, the magistrate hearing functions as the trial, and the Ranger who issued the citation has the dual role of prosecutor and prosecution witness.

National Park Service areas differ greatly in the amount of vandalism they receive. I have had the privilege and pleasure of working at some of our more remote areas, including Isle Royale National Park, a 210-square-mile island in Lake Superior, and Katmai National Monument, a 4200-square-mile wilderness in Alaska. I have also worked at Joshua Tree National Monument, a beautiful desert area north of Palm Springs. Joshua Tree has a large number of visitors, especially in the spring and fall, and most of them, it seems, are fr the Los Angeles-San Bernardino area, from wh it is a 2-hour ride over Interstate 10 to th Monument. When I worked there, we had our fair share of vandalism, primarily such acti ities as driving motorbikes off the roads an painting the rocks. The problems were not i ordinate, but they were always there.

Conditions were different at Isle Royal A person wanting to visit the island had to make reservations in advance for a 73-mile boat trip from Houghton, Michigan, which cos a minimum of $20 and took 8 hours, over one the roughest freshwater lakes in the world. It seemed to follow that only people who rea cared about the kind of place that wildernes island was would take the time to make the trip out. We had so few vandalism problems that it was truly idyllic. Oh, occasionally someone might throw down a piece of paper, but the next visitor coming along would pick it up; and every once in a great while some young person (usually a boy in an olive gree uniform in the company of several more young men dressed similarly) might carve upon an aspen tree, but woe to be to him if some oth visitor saw the act.

There are various reasons why some plac are more prone to vandalism than others. Pe haps those which are harder to visit attract mostly those who care; consequently, problem are minimal. Many other factors also appear to have an influence: the design of a facili the appropriateness of a sign (often a regulatory sign that isn't really necessary seem to attract abuse as the only means the publi has of expressing their frustration and indi nation); and the degree to which an area is kept up (we all know that one broken window in a building seems to lead to many more or that one set of initials on a rock seems to overnight--literally--propogate several others).

Frustration is probably one important reason for vandalism. Perhaps a desire for immortality accounts for the names and initi on many rocks and trees. And, of course, ma acts of vandalism result from simple lack of appreciation or understanding of those featu that we who work in a park consider so impor tant.

It is no closely guarded secret that we in the National Park Service are understaffe and we long ago found out that we don't have enough Rangers to place one behind every tre in the hope of catching some violator. We also long ago discovered that if we could talk to a visitor before he commenced his pa experience, the chances were good that he would have a more enjoyable visit, all other

things being equal, if we could gain the visitor's interest and give him some knowledge, chances were good that we would have no problems with either deliberate or inadvertent vandalism (or any other law enforcement problem).

Interpretation has several meanings, but in its purest sense it seems to me a very Socratic principle: to help someone else understand better an idea or an object or a value--not to explain it to the other person, but to be a vehicle by which he may discover the proper answer himself. This is often a lengthy process and one which we engaged in law enforcement may not have time for. But in the National Parks, at least, we simply cannot afford to divorce interpretation from protection. We have found that just <u>any</u> form of positive communication with a visitor, whether it's talking about the values of an area, or even just reminding him of our more commonly violated rules and regulations, stands a good chance of insuring that your next contact will not be a law enforcement one.

In parks where personnel are spread so thin that law enforcement Rangers must constantly patrol just to cover the assigned "beat", I will admit that their presence alone is a deterrent to a certain extent. But, in the long run (and often even in the short run), it is not enough. Ultimately, those visitors who <u>understand</u> what you are trying to provide in an area, and who are even a bit protective about it, are the ones who will help to lessen the problem of vandalism. To my mind, law enforcement, by itself, will never be enough.

A Magistrate's View of Vandalism

Willard W. McEwen[1]

As a comparatively new U.S. Magistrate it has been a real "eye opener" to view my calendar on the third Friday of each month and see from 50 to 150 arraignments set for misdemeanors allegedly committed in the National Forest area behind Santa Barbara. Approximately 40 percent of this number relate to vandalism.

I was raised in Santa Barbara and spent much of my youth in Boy Scout and Explorer activities relating to the "back country." I own a small cabin on Figueroa Mountain and I'm quite familiar with the geographical area within which these offenses are committed. A defense attorney might consider filing an appropriate affidavit of prejudice on that basis, but thus far it has not occurred. I readily admit that I am "prosecution" oriented; that is, I find it difficult to tolerate the treatment which public facilities receive from the majority of the defendants who appear before me, and I continually search for appropriate lectures and dissertations to express my concern when passing sentence. Concurrently, I search for a sentence that will be meaningful to the defendant and perhaps serve as an example to friends and acquaintances, thereby discouraging similar conduct on their part.

We have worked out a sentence system similar to that of the Valyermo Ranger District--pay the fine, serve time in jail, or work off the fine ($25.00 per day) in the Los Padres National Forest. In a few "hard core" cases I utilize the Probation Department to supervise the defendant's conduct.

A major concern I have relates to the fact that the majority of those defendants who elect to "work off" their fine are those who are not charged with the aggravated offenses. Usually they have camped in an undesignated area or entered a closed area, etc., and they are more or less the "good kids"; their offense was inadvertent or unintentional. I rarely receive these defendants back before me on a repeat offense. I do, however, receive an increasing number of defendants who are charged with, and ultimately found guilty of, aggravated offenses (destruction of public property, assault on Forest officers, use of narcotics, etc). We're now averaging seven trials per month and approximately 90 percent of the defendants are found guilty.

I can only conclude that the sentencing procedure which I have adopted is not serving a meaningful purpose as a deterrent, and that the law enforcement and Forest Service officers (and employees) concerned should, perhaps, make some recommendations to the Presiding Magistrate and to me personally on this subject.

[1] United States Magistrate, Santa Barbara, California.

I feel that we have reached a state where the "majority" of campers who use our back country are no longer the "good guys." I think that a majority, or at least a substantial minority, are "bad guys"; i.e., vandals and others who can only be properly discouraged by the establishment of an entrance and exit gate system with appropriate fees charged to absorb the administrative expense. We no longer live in a country with a substantial number of poor people. Almost every camper would be happy and able to pay a reasonable fee for use of nicely maintained camping and recreational facilities. The most important factor is that the campers' names and license numbers would be registered as they entered, and this, I believe, would discourage them from indulging in destructive activities.

One last important point is that I continually listen to the defendant relating "extenuating circumstances" that will, he hopes, soften the sentence to be imposed. Almost inevitably the defendant will state: "There wasn't any sign prohibiting nude swimming," or "We just pulled in to the camp and didn't know that any fee was due," or "There was no sign showing this to be a closed area." I always advise them that it is their obligation to visit the nearest ranger station and ascertain the rules and regulations that govern the recreational use of the area and conduct themselves accordingly. This "sounds" good but in fact demonstrates that the Forest Service has insufficient funds and personnel to post these areas with appropriate signs containing the rules and regulations, whereas the camper who stops at a road stop gate can be immediately advised and will have little or no excuse for deviation from the said rules and regulations.

It is quite apparent that some changes must be made. I would strongly support the establishment of check stations and fee structures that would properly defray the overhead expenses, including the necessary assignment of local police and sheriff employees to these areas. Santa Barbara is fortunate in having good men available, but how long the County budget will be able to pay for their services is a matter of continual concern.

Creative Justice

Glenn Hampton[1]

The subject I will briefly discuss is one we, as resource managers, have no control over but should have positive input to--the justice system. A number of years ago a very creative judge in Antelope Valley, California, initiated a Court Referral Program, by which persons guilty of certain misdemeanors were allowed to work off their sentences on the National Forest. The judge gave offenders three choices: pay a fine, go to the slammer, or work off their sentence in the adjacent Angeles National Forest. Most violators chose working in the National Forest.

The Court Crew Program started on the Valyermo District of the Angeles National Forest in 1964, when two high school boys who had chopped down an oak tree were sentenced to plant and water seedlings over their Christmas holiday. Both boys wrote to the judge and thanked him for the fair sentence. Since that time, the program has saved taxpayers well over $500,000 on this one Ranger District. This does not include dollars saved in reduced costs of maintaining penal inmates, or in such activities as fire prevention, resource management projects, and human resource rehabilitation. It also doesn't include dollars saved in other areas where the program is in progress. The most dramatic proof of its success lies in the fact that many other judicial districts throughout California are now in the program.

For years many jurisdictions were reluctant to employ the program because of the cloudy legal area of compensation for injuries. We've solved this problem with passage of the National Volunteer Act. All court crew personnel are now fully covered in case of an accident.

The accomplishments in environmental gains and overall improvements are numerous. Examples are reforestation, wildlife habitat improvement, fire prevention, road maintenance, trail construction, and campground construction and maintenance.

[1] District Ranger, Valyermo Ranger District, Angeles National Forest, Forest Service, U.S. Department of Agriculture, Pearblossom, California.

Although I've mentioned the dollar savings I think the real value of the program lies in the human values. Here are a few advantages of the program to the offender:

1. For an individual who is unable to pay a fine, it removes the burden and stigma of a jail sentence.

2. For young offenders, it takes the financial burden of paying a fine off the parents' shoulders and lets the offender serve his own sentence--thus teaching him personal responsibility. Many young people are exceptionally antagonistic toward the law enforcement agencies and officers. This program helps them to feel that law enforcement sees them as individuals, and that the system is not unfair or harsh with the first offender, who may have committed only a minor offense. Also, not being treated as a criminal sometimes helps put in check an otherwise rebellious young person.

3. Families already receiving County aid or some other form of public assistance need not further tax the public moneys by having a family member in jail.

4. The work accomplished is productive and important and the person doing the work knows he's doing something constructive. It often gives him a feeling of pride in accomplishment and strengthens his "work ethic."

5. The program allows people to work on their days off or vacation time, so that they are not in jeopardy of losing their livelihood.

The court crews have been a tremendous help in doing nontechnical tasks and freeing Forest Service personnel for more highly skilled and technical activities. When skilled people are sentenced they are fully utilized in projects needing carpenters, contractors, painters, etc.

There are also advantages to the community:

1. There is a minimum cost to maintain the program--clerical time at court and on the Forest district.

2. Instead of costing the County for a day in jail, the offender benefits the County and local community in labor for each day he works.

3. Every offender personally contributes his time to a constructive work project, thus compensating society for his offense.

4. The educational value of introducing the court crew member to the practice of conservation and expanding his environmental awareness is worth many times more than the project value.

Work accomplished by court crewmen does not duplicate and/or replace work contracted between Congress and the Forest Service. Permanent government employees are not replaced by court crewmen. Most of the work is resource-oriented work that must be accomplished in the years ahead.

The Court Referral Program is not an alternative to the rehabilitation of a convicted criminal. It is designed as a form of rehabilitation for misdemeanors. And as statistics point out, over and over again, most first-time youthful offenders are only guilty of a misdemeanor. All too often they feel they received a raw deal and a jail sentence only increases their bitterness. Or, their parents pay the fine and the young person goes free--free from financial and personal responsibility. Because we have long rejected the goal of retribution as a legitimate aim of the criminal law and of sentencing, the only remaining method by which the general public may be protected is the reformation of the individual offender into a law-abiding citizen.

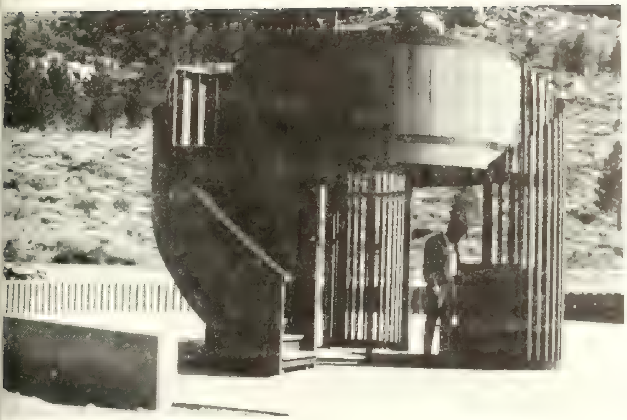
The Court Referral Program has been in existence for 10 years. Returnees make up less than 5 to 10 percent. That's an outstanding record when compared to the national one. Many court referral people return, but as volunteers--to work on conservation projects with their four-wheel drive clubs, etc. This is a testamonial to the human value of the program.

Legally, the rational application of the doctrine of the "least drastic alternative" preserves both of the conflicting values: the need of society and the integrity of the Constitution. The United States Supreme Court has often used the phrase "less drastic means" in a First Amendment context.

It appears inevitable to me that courts ultimately will adopt, in one form or another, the doctrine of the "least drastic alternative." The doctrine is hardly extreme. The American Law Institute has recommended a presumption in favor of probation of every offender. The American Bar Association has declared that nonconfinement is to be preferred over total or partial confinement in the absence of affirmative reasons to the contrary.

All the National Forests and some of the Ranger Districts represented here today are located in communities where there are Municipal Courts. Go visit the judge or District Attorney or Magistrate and see if you can work out a Court Referral Program.

DESIGN AND VANDALISM



The Designer as the Vandal

Michael Morrissey[1]

As our nation's population continues to increase and our cities become more overcrowded and impersonal, the desire to get away from it all and get back to nature becomes more and more important to everyone. Our increased affluence has directly affected our mobility and indirectly resulted in reduced time spent on the job. In recent years, we have been experiencing a trend toward shorter work weeks and longer annual vacations, enabling more people to travel further away from population centers and in larger numbers than ever before to outdoor recreation facilities. This available free time and new-found mobility now gives us more leisure time for outdoor recreation. A byproduct of this increase in people fleeing to the National Parks and Forest has been a steady rise in vandalism. The increase is partly due to overuse, to inadequate, improperly designed facilities, and to the ignorance or malice of the user.

The National Parks and National Forests do not in themselves contribute to these phenomena, but they directly suffer from it. They represent the authority and provide the essentials for an active vandalism program: soft workable material such as tree bark and picnic tables; and metal signs--excellent targets for the catchless hunter. The sign becomes the aggressor in the wilderness experience or even on a day hike. Recreationists go to a great deal of trouble and expense to remove themselves from their daily routine and surroundings. They are looking for a different experience--"nature." Man-made structures, of which the sign is an example, are all-too-familiar reminders of what they are trying to get away from--directives. Man-made structures in a natural setting are mutations, recognized by the visitor as targets to be shot at and defaced.

What is vandalism? Vandalism is destroying or defacing someone else's property. At publicly operated facilities, vandalism is the modification of a given object or landscape to suit the needs of the individual, be it for pleasure or purpose. Vandalism takes the form of carving, burning, spray painting, littering, breaking, dismantling, or shooting. These acts are most often directed toward signs, trash cans, restroom facilities, and other man-made facilities. Frequently, nearby trees and vegetation are also the target of the vandal.

Vandalism is an act directed toward a particular object or serving to make a philosophical statement. If the act is committed against an object, then the object must be examined to determine the reason it is producing deviant behavior. The designer and managing agency are responsible for determining why the vandalism is occurring. This form of vandalism is agency/designer initiated, and can be reduced or eliminated when a method is implemented to identify and resolve the problem. The method is the development of a communication feedback system, one that will facilitate a dialog between the designer, management, and the recreational user. Because the user and operating agency are usually in direct contact with each other, a form of communication already exists--it is the designer who is usually isolated. Too often the designer's responsibility ends with the completion of construction.

Vandalism as a philosophical statement is a sociological problem. At best, the designer can only facilitate this type of activity or ignore it. The designer can not prevent sociological vandalism. When it is stopped in one place it usually appears in another.

If shot-up signs and toilet structures represent aggression and hostility directed at an authority, the parks and forests, and the government, then designing bullet-proof signs and toilet structures does not solve the initial problem. The vandal only moves on to more vulnerable targets or changes his style of vandalism.

Vandalism is also a form of communication. The vandal is saying to the designer, management, or even to society--"I don't like what you have done and I'm going to change it."

The people who rip off the top of the picnic table or the loose board on the storage

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shed to build a campfire are not vandals. They are recreationists looking for firewood. What is a camping trip without a campfire? If a recreationist has to do this, then vandalism is purposeful and necessary, though purposeful only to the vandal.

Many generalizations could be made about who vandals are--teenagers, those people from the city, etc.--but this would serve no purpose in increasing understanding of the causes of vandalism for the designer. Each individual and type of vandal must be examined because vandalism is an act committed by individuals, not by a homogeneous group. On the other hand, there is one group of vandals who can be examined more closely than the others because we know more about them. They are the designers and planners of outdoor recreational facilities. Their selection of inappropriate material, their acceptance of poor construction and poor site design, and their misunderstanding of maintenance needs and durability has lead to a substantial amount of the damage called vandalism. Misunderstanding and ignorance on the part of the user and the operation and maintenance crews results in vandalizing of newly constructed facilities. The picnic table is an example. The vandal sees the wooden picnic table as a source of firewood and a whittling block. The operator and maintenance crew feel the concrete picnic table solves many of the repair and maintenance problems created by the vandal. The designer searches for indestructible material that looks and feels like wood, but won't burn and can't be carved. Yet, all the recreationists wanted was a flat area to put their blanket on or a simple seating arrangement to keep them off the ground. At times, we have let the vandal become the designer and inadvertently the designer has become the vandal.

Where do we go from here? We must first accept that vandalism can not be stopped; it is here to stay. At best, we can only minimize the discomfort to the user and the cost of vandalism. We must recognize there is no absolute solution to vandalism. What appears as a solution in one situation, may not work in another.

One problem confronting National or State agencies is that each jurisdiction covers many different and varied types of subcultures, each one producing its own form of vandalism. The most practical path toward a solution to vandalism is to open communication between the designer, the operator, and most important of all, the recreationist.

Control of Vandalism--An Architectural Design Approach

John Grosvenor[1]

In discussing the Forest Service architectural design approach to vandalism in recreation structures, I will touch on three types of abuse. The most obvious is overt human actions, such as defacing buildings and breaking items. But there are also two additional types to consider. One is covert human actions--unthinking destruction and mistreatment of facilities, such as flushing down toilets objects that disrupt sewage septic action or plug the waste lines, pouring gasoline or other volatile liquids into vault toilets, or leaving doors or windows open to the elements to be damaged by wind, rain, snow and ice. The third type of vandalism is nonhuman damage created by natural agents, including water in its various forms, earthquakes, or various animals and birds.

The earliest Forest Service toilet structures were very primitive and simple, with rough sawn wood, concrete block, or stone masonry exteriors. The interiors were of similar character. Public use was low; therefore, vandalism was slight. After World War II and in the early 1960's, many more people were using National Forest campgrounds, and with this increase of usage came more vandalism. The architechtural designs became larger and more sophisticated and the materials more finished, so that the repair costs of vandalism increased greatly. Attempts were made to use materials and finishes that might deter or stop abuse. These included plywood interior walls with joints sealed and flush, then painted with a two-part epoxy paint. Extra blocking and backing were added to toilet enclosures, doors, and windows, and details were simplified to keep repair costs down. Floors were treated with epoxy and exterior finishes were natural.

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[1] Architect, California Region, Forest Service, U.S. Department of Agriculture, Pleasant Hill, California.

As we moved into the late 1960's, public usage was increasing even more, so even bigger and more complicated buildings were designed and constructed. We were still looking toward preventing overt vandalism in the designs and materials, but at this time we also began to face the other two types of vandalism. Oversized waste lines were put in to accommodate rocks, sanitary napkins, and plastic bags. The height and location of water closets and urinals for use by children and the handicapped were considered. Larger door closers were used to resist wind damage. Windows were eliminated and skylights or clearstories were added to bring in natural light. To provide heat to keep pipes from freezing in spring and fall, tamper-proof electric heaters were found. The type of glue used in the plywood, the species of trim, and the type of roofing materials were considered in areas where animal vandalism was prevalent (porcupines have eaten exterior plywood and woodpeckers have ruined trim and roofs.

As we entered the 1970's, the cost of maintenance and the amount of vandalism had again increased, together with the number of public users, to a point where new design approaches were needed. With the increased construction costs, we found it necessary to reduce the size of the buildings to stay within our budgets. About this time, we discovered that esthetics were a factor in deterring vandalism; more pleasing buildings, lighter interiors, and good quality materials seemed to keep the public from vandalizing our buildings. On the other hand heavy, dark, dank spaces seemed to increase public misuses. With the decrease in the size of the building and to keep the scale of the structure appropriate for the location, we tried turning the axis of our roofs 45°, giving us what we called the "handkerchief roof."

In 1972, the Forest Service began an extensive water-pollution abatement program, during which hundreds of old toilet buildings were replaced with modern sanitary structures. Again construction and maintenance costs were soaring much faster than money was becoming available. In order to better utilize the funds available, the concept of separate men's and women's toilets was dropped, and the water closets assigned to a campground were placed in separate cubicles, each with an exterior lockable door. Once more materials were carefully studied to give functional, attractive, easily maintained buildings. Split-faced concrete blocks with integral coloring selected for the specific campground was used for the exteriors. Easily cleanable interiors (factory-applied epoxy finish or ceramic tile) were chosen. The need for fragile toilet partitions was eliminated by the either-sex concept, and an easily accessible pipe chase also held the electrical equipment and allowed space for storage of supplies. Interior lights were also placed in the pipe chase to keep public access down and reduce damage and theft. Exterior lights were specially designed for our buildings to be vandal-resistant. Floors were drained into the pipe chase with only one floor drain per building. Natural light was brought in through the roof to keep the interior of the buildings well illuminated. Ventilation was introduced at the top of the block walls, with closure panels to be installed in the winter. The designs were again moving towards the simple but rustic approach with heavy flat wood beam roofs and rough concrete block walls.

Up to this point, I have been talking only about toilet buildings, but the Forest Service has many other types of public use recreational structures. Our play structures are simple, rugged, and very natural. Native materials are used with natural finishes. The scale of these structures is designed for the users. We have had very little vandalism. Foot bridges in our campgrounds have been designed using low maintenance, damage-resistant materials, cor-ten steel open-web joists, heavy natural redwood handrails and decking, and exposed aggregate concrete abutments. Our designs for drinking fountains again are simple and natural, using heavy timber or stone pedestals and stainless steel bowls.

A fairly recent addition to our campground has been entrance stations. With these buildings we have tried to establish an architectural style for our campgrounds. They have been in character; therefore, we have used lexon-type plastic windows to deter vandalism, with shutters for the winter season. The materials have been rugged (heavy timber or concrete block) with natural finishes. Another new addition has been overlook structures along road systems and along reservoirs. These have been designed to invite people to use them, and have been open and clean to reduce vandalism. Again, natural finishes and vandal-resistant materials have been employed.

In our visitor center we have been aware of the possible effects of natural elements as well as human vandalism. Native stone, concrete, and heavy timber are used to create a building which is resistant to all three types of vandalism. Materials and design concepts have been used to create many structures which express a rustic bold character and invite the public to use them. Hopefully, the new designs will not only invite use, but vandalism-free use.

Design of Campground Facilities

Briar Cook[1]

Why do people vandalize outdoor recreation sites--areas that have been designed for their enjoyment? Many reasons have been offered, and the following may be most applicable to recreation areas and facilities:

a. Facilities are poorly maintained or improperly constructed;

b. Attention-getting or competition is stimulated when some groups of people get together;

c. Some people may have a bad feeling toward an organization and it is a form of "getting even;"

d. Lack of activity in an area creates boredom;

e. Some people simply get a kick out of destroying things.

The targets for vandalism in outdoor recreation areas usually include toilets, picnic tables, fire grates, garbage cans, buildings, and virtually any other object.

There is no possible way to anticipate or stop vandalism without an inexhaustible budget and staff. The best approach is to examine the most frequent vandalism occurrences and design facilities to help eliminate any recurrence or to lessen the extent of the vandalism.

The following recommendations are drawn from our recent work on toilet and table design.

VAULT TOILETS

Wherever possible, vault toilets should be converted to low-volume water or oil recirculation toilets. A booklet on maintenance and design of vault toilets is available from the author.

Building Interior

The interior of the toilet building should be clean and odorless. This can be accomplished by proper venting, and by sealing concrete floors, using monolithic fiberglass interior liners, and using proper paints for the interior. The monolithic fiberglass interior liner is constructed much like a shower stall and is in one piece with the toilet riser built in. The toilet seat is similar to a household seat instead of a small metal camper-type seat. There are no cracks or sharp corners where debris can collect. Building design should allow for easy removal of damaged liners.

Paper dispensers should be designed to accommodate more than one roll of paper per toilet seat, depending on the frequency of maintenance visits. A two-roll dispenser or a simple locked bar that will accommodate many rolls, designed so the bar will not allow the paper to roll off easily, could be used.

All floor surfaces should be completely sealed to prevent staining and odor absorption and to make cleaning easier.

If lighting panels are used, they should be nonbreakable. Lights should be considered for night use, even if they have to be battery run.

Floor-level vents on two sides of the building are essential for ventilation and evaporation of cleaning water and urine deposits. These vents must be constructed of sturdy material in order to be vandal-proof. The screens should be located so as to prevent people from kicking them out. In a slump-stone building, place the screens between two decorative slump-stone blocks (blocks with many holes).

Building Exterior

Metal doors may prove more durable than wooden doors. Hydraulic door closures are being used to help prevent people from slamming doors.

All exterior concrete slabs and concrete

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[1] Staff Engineer, Environmental, San Dimas Equipment Development Center, Forest Service, U.S. Department of Agriculture, San Dimas, California.

block or slump-stone should be sealed with a clear concrete sealer. This is to prevent paint from being absorbed into the block or slump stone, and to make its removal easier. If the concrete slab all around the building is sealed, stains will not be so noticeable when the interior is washed out or when the vault is pumped.

All signs should be securely bolted to the concrete block, slump-stone, or exterior wood frame.

Venting Techniques

Proper venting can by itself eliminate most odor problems during the use periods. The size of the vent should be the same as the accumulative size of the vault toilet riser openings. For every vault toilet seat, approximately 100 square inches of vent area is required. The vent should go from the vault through the building and terminate at the ceiling level. Insulation should be placed on the joists within the attic so that the heat generated in the attic will not permeate the use compartment. The roofing material and construction should be such as to induce solar heat into the attic. A vent, a little larger than the vent terminating at the ceiling level, should be constructed through the roof so that it is above the ridge height. This vent should be screened for flies.

The sun will heat the attic causing the hot air to rise, and air will be pulled down into the vault through the toilet seat. Thus, the odor in the use compartment will be eliminated. Some large rocks or other heat-absorbent material placed in the attic may keep this flow of air going on into the early evening.

A rain cap should be placed on the roof vent to keep water out of the attic. The bottom of the rain cap should be at least 3 inches above the top of the vent pipe so that the wind can flow easily between the two. The aspiration of the attic air due to wind is nearly as effective as the solar heat effect.

Vault Design

The vault should have an impermeable liner or container (either Hypalon or cross-linked polyethylene). It should be sloped 1 inch per foot from inside the building to outside, should be no greater than 4 feet deep, and should have a minimum 24-inch-diameter manhole cover on the outside of the building (to the rear or side).

Fiberglass, concrete, or steel should not be considered for the vault portion of the toilet unless the concrete is acting as a container for Hypalon or cross-linked polyethylene.

FLUSH TOILETS

Building Interior

Wall-hung urinals should be adjusted so that both children and adults can use them. Floor-mounted units satisfy all needs. Partitions next to urinals should be designed to withstand the corrosive effect or urine.

If water closets for the handicapped are used, a regular one should be installed also. Children and small adults have a hard time using the water closets for the handicapped.

No wood paneling should be adjacent to the water closets or urinals because users will carve on them. All floors should be heavily sealed to prevent absorption of odors and to make cleaning easier.

All faucets should be foot or knee operated, with 1 gallon per minute flow control devices placed in the lines. This will prevent a great deal of cleanup maintenance by keeping the bowls and fixtures cleaner. Paper dispensers should be designed for more than one roll.

The interior should be well lighted and easily cleaned.

Building Exterior

The material used on the exterior should be functional, locally available, and inexpensive. The privacy screens should be primarily functional, rather than esthetic. If concrete or slump-stone is used, it should be sealed with a concrete sealer.

PICNIC TABLES

Fiberglass picnic tables or covers for existing wood tables can be made to very closely resemble wood, to be heat resistant, and to resist carving with knives. The fiberglass helps prevent food from being absorbed into the surface of the existing wood tables and presents a cleanable surface: a damp cloth will clean off most normally present food remains.

In conclusion, all designs should be geared toward the conditions in a given area rather than to satisfy a designer's ego.

Design vs. Vandalism

Arthur C. Danielian[1]

Public schools, civic centers, public libraries, youth activity and recreation centers, and other public-use facilities in urban or suburban places are designed by architectural firms in the private sector for various governmental agencies. Each project is designed in response to criteria, including budget limitations, developed by the administrative agency. The architect, during the design process on all types of buildings, must maintain a proper perspective and sensitivity with respect to numerous design considerations, including vandalism. The level or priority of the design criterion related to the durability or indestructibility of a structure must be weighed carefully. Nothing prevents the architect from designing completely indestructible buildings, other than his desire to satisfy more heavily weighted considerations and budget restraints.

Good architecture is the proper blending of basic considerations of function, economics, and esthetics. In the absence of concern for economics, for instance, the designer might produce a piece of sculpture, not architecture. In establishing priorities or placing emphasis on any particular design consideration, whether it be concern for vandalism or concern for delicate design, the architect must be aware of these underlying influences related to the urban-setting:

Social-economic conditions

Age of community

Relative crime rate and trends

Attitudes and values of the people

Density or the level of community anonymity and

Existing level and respect of urban quality.

The relative strengths of these elements have important influence on the design. The architectural solution for a new teen center in an old and economically deteriorated community with high vandalism rates will be quite different from one designed for a new community whose crime rate and related costs are not as sensitive issues. Similarly, a toilet facility located in wildland areas, where the effects of vandalism absorb perhaps 60 percent of the operating budget, is likely to require far more concern for durability than a teen center in a new suburban community where vandalism might account for less than 3 percent of the operating budget.

Too often, buildings are designed with little or no respect to considerations of life cycle vs. initial cost. For example, the cost to maintain a public school over its life span of 50 years is some 10 times its initial construction cost; yet in most cases, the budgets established for such structures preclude the use of optimum quality materials, which may cost more initially but in the long haul save substantially more. Budgets for buildings, especially high-public-use structures, should be determined from life cycle studies, not by arbitrary limits. The architect working with his client can most effectively establish the appropriate budget for any given project during the initial or conceptual phase of design.

Let us examine a few good and bad concepts of site planning, architectural design material specifications, and landscape design, to highlight problems of vandalism and some potential solutions.

Older communities, especially in deteriorated and abandoned areas, become attractive nuisances or targets for vandals. Conversely, in lively areas, where multiple activities involve people, the people themselves become natural deterrents to acts of mischievous vandalism.

It's unfortunate that some magnificent public spaces, such as the Santa Ana Civic Center, are planned for shamefully limited use. These vast-scale and richly developed urban spaces are used only during normal working hours. A mixture of public, quasi-public, and private commercial uses could have enhanced and expanded the use activities into

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[1] President, Danielian, Moon, Ilg and Associates, Architects/Planners, Newport Beach, California.

the evening and weekend periods. The provincial attitudes of governmental agency planners are responsible for such shortcomings in many urban places. Programing and planning of such centers, as well as smaller-scale government improvements, should be handled more creatively and with input from the private sector to promote more interest and vitality, lessen tactical vandalism (demonstrative type), and maximize returns on public investment.

Vandalism could be deterred in many public or private developments, such as schools, if more design consideration were given to building arrangements, court yards fencing, and screenwalls. A good example is the intermediate school, where a single, self-contained structure with only four entry points can reduce problems associated with vandalism. All entry points were exposed to natural surveillance. Once in the building, secondary entry doors are used to separate evening public use facilities, such as an auditorium, from internal use areas, such as the administrative offices and cafeteria. With a reduced number of entry points, with easy visual and physical access, and with no exterior windows, a school will experience less vandalism, require less maintenance, and be more productive on less land. Another example of good planning is the introduction of semi-interior courts which can be closed off at need with a well-designed rolling fence. Vertical bar spacing should be close enough to prohibit a child from squeezing through but maintain a sense of visual openness to attractively landscaped areas. Again, the concept of natural visual surveillance is retained.

The importance of good surveillance cannot be overemphasized. Entry areas, especially those of public buildings, can best be controlled when they are oriented to public view from the outside, or to a receptionist's or director's view from the inside. An obscure or shielded entry area becomes an attractive nuisance in the dark. Another technique to discourage vandalism is induced self-restraint by threat or intimidation. Just as department and grocery stores have one-way glass at strategic points, a dark glass window on a structure adjacent to an outdoor recreation area such as a swimming pool or tennis court can have psychological effect in giving potential vandals the sense of being watched.

In general circulation areas, traffic can be directed or discouraged by creating a sense of private territorial domain. The use of wing walls, change of levels, barrier-type landscape treatments or textures can subtly separate adjoining public and private spaces without overuse of walls or other imposing structures. Most architects have a good understanding of human behavior, and through relatively simple applications of design concepts can direct the movement of people and minimize their interest in adjoining spaces not intended for public use.

Wall surfaces are one of the favorite attractions of vandals. Some communities have serious problems with graffiti. Graffiti is a form of social protest, and fairly typical in communities where socio-economic conditions have been allowed to deteriorate and where recreational opportunities are inadequate. Wall surfaces can frequently be protected from becoming attractive nuisances. Separating walls from public walkways with landscaping and utilizing textured surfaces like split-face masonry are only two ideas. Sealing the surfaces of textured walls will usually reduce the effort needed to remove aerosol markings without sandblasting. Durability of vertical surfaces, especially around entry ways, should receive special attention in design.

Finally, greenbelt and parking-lot lighting is important. A well-lit parking lot is subject to a minimum of vandalism and crime. Also, from a marketing point of view, a parking lot associated with a structure designed for night use but not illuminated is inadvisable because it will tend to keep patrons away, especially women.

Following are some predesign and design considerations that may prove helpful to agency administrators faced with problems of vandalism and seeking sound solutions through effective site and facility design.

General Predesign Considerations

Procedure for Selecting Architects--Agencies should not make selections on the basis of low bid. Rather, several architects who have demonstrated competence and sensitivity to good design should be solicited for proposals, and a personal interview should be held. Fees should be negotiated after the most appropriate architect is selected. (Many agencies are already using this approach.)

Design Criteria or Program--Rigid criteria can stifle an imaginative solution. General criteria expressed in terms of desired performance rather than specification will yield superior solutions. Final budgets should be confirmed by the architect early in the design development.

Comprehensive Team Approach--In addition to the architect, other required consultants must be carefully selected. The qualification and experience of the design team, their approach to design, their ability to work together, and current work loads should be considered. The architect is normally the most

appropriate person to organize and coordinate the total team. A flow chart is a very effective way to analyze, distribute and coordinate the preconstruction activities. It encourages a comprehensive recognition of the problems, arranges for orderly and timely inputs and maximizes the effectiveness of the program.

Site and Building Design Considerations to Minimize Vandalism and Crime

Parking Next to Buildings--Parking of vehicles against or adjacent to a building is not recommended. Vehicles act as screens to hide behind and are closer for get-away purposes.

Parking Lot Lighting--Good lighting layout, well spread throughout the lot, discourages parking in dark areas by would-be vandals or criminals.

Security Lighting Around Buildings--Good lighting all around the buildings is the best investment. A well-lighted building discourages attempts at unlawful activities.

Lighting at Vulnerable Points--If total lighting around entire building is not affordable, then lighting should be concentrated at least around exterior openings, such as entry doors, windows, intake/exhaust louvers, grills, panels, ladders, etc.

Security Fences--Fences 8 feet high and gates fabricated from metal or masonry are desirable between the parking lot and the building. Fences and walls are additional physical barriers to overcome. Lighting should be located along these fences. Open-type ornamental iron or chain-link fences are desirable because they allow visibility.

Appurtenances Around the Building--Storage areas, trash enclosures, lean-to's, or other such appurtenances near or adjacent to buildings should be kept to a minimum: they are potential hiding places and encourage vandalism.

Doors--Exterior doors should be solid-core material or hollow metal, set in heavy-duty wood or metal frames. Doors should be equipped with nonremovable hinges. Glass in aluminum doors should be well lit.

Locks--Generally, heavy-duty locks with a long bolt through them should be used. Dead bolts on the inside of doors should be used where feasible and legal.

Sound Alarm Devices--Sound alarm devices on exterior doors can be used. Unauthorized personnel without keys cannot open doors without tripping the sound alarm.

Window Frames--Heavy-gauge aluminum window frames are recommended. Jalousie (slatted louvers) windows are an invitation to a burglar.

Plastic vs. Glass Windows--Almost indestructivle, clear plastic material, which comes in various sizes and thicknesses, is available. Cost, however, is higher (about 75 to 100 percent) than that for glass. Unless absolutely necessary, plastic glazing should not be used at eye level (because of distortion) or at a level of physical reach (because it is easily stretched). For clearstory glazing it is excellent.

Ladders--Exterior ladders attached to buildings for access to the roof should be well lit. Unless required by code, interior ladders are preferable. Ladders in general are attractive nuisances.

Security Bars/Grills--Roof openings and access points should be equipped with security bars and grills. Cost is nominal and savings could be substantial. Keep in mind, however, that these devices can also create entrapments for people inside a burning building.

Surveillance Systems--These systems are gaining popularity and newer and more effective systems are constantly being developed for the consumer. Costs are coming down, as competition is keen, but the cost of a system usually depends on its degree of sophistication and the number of openings or areas it covers.

Conclusion and Overview

In conclusion, it is apparent that the architect cannot eliminate vandalism; he can, however, through design, influence the behavior patterns of people who utilize spaces, indoors or outdoors, day or night.

Generally, the problems existing in our wildland areas are no different from those in our more urban areas. Inadequate revenues to public agencies offset the increased demands for expansion, redevelopment, and upkeep; the need for increased services; and inadequate general plans are the major stumbling blocks. These problems can no longer receive the "band-aid" treatment, as evidenced by more and more urban failures. The time has come when we must now focus on comprehensive planning if we are serious about resolving our current and future problems. The planning process would include analyzing the long-range needs, evaluating our physical potential, considering the continual need to improve the quality and longevity of our natural wildland areas, and realistically reconciling financial requirements with programed revenues, public and private.

Preventive Planning to Reduce Vandalism

H. Ernest Reynolds[1]

The widespread and growing problem of vandalism can only be solved if we make dramatic changes in our planning process. The old approaches are not working, so let's think creatively toward a new approach.

Our firm is currently compiling the results of a questionnaire sent to park directors in selected cities and counties throughout California. So far we've had a 30 percent response, which is fantastic. It shows the intense interest in park financing, maintenance, and operation. The preliminary data also show the increasing problem of vandalism.

Parks have been a very important part of my entire life. I've worked in them, played in them, planned them, and devoted years to discovering ways to make them serve the public better while at the same time preserving environmental values. It's because of my sincere personal and professional interest that I value this opportunity to share 10 ideas for reducing park vandalism.

1--Identify your vandal. Remember that your vandal is also your park user. Who are the groups who desecrate our parks? Have you ever tried to identify them? I know from my experience that some of these are interest groups we have ignored over the years. There probably isn't any park manager who hasn't turned his back on permitting two-wheeled bikes, four-wheeled off-roaders, skateboarders, hang gliders, gun clubs, even nudies from using our parks. Perhaps some of the vandalism is due to the people that we have kept out of our parks. We should ask ourselves whom we have left out and why.

How would you feel as an urban resident if you arrived at a remote campground and you found the same system used as in the super market checkout stand to gain access to a camping spot? Then, to make it worse, you found that the camping area was designed for a different type of camping vehicle from yours. What thoughts run through your mind when you go into a camp area planning to gather wood for fire and you find out that it is not allowed? You probably end up driving to the general store and paying a fancy price for charcoal briquettes. Might the thought just run through your mind that you would sneak out into the woods and collect some wood for your fire? And thereby be considered a vandal?

Let's take another example in an urban park. The Planning Department of a city decides that a particular area should be mainly inexpensive homes with three or four bedrooms. This means that there will be many mothers and tots. This further means that the community park will likely be designed specifically for these users. What happens to the 11- to 15-year olds? If you have ever had any children of junior high school age, I think you'll agree that they are the most active and orneriest group imaginable. Yet, we plan our parks so that they have little appeal to this group during the daytime. Instead, they gather in groups at night, where the temptation is great to show off their budding maturity by acts of vandalism.

Aren't we as planners, foresters, and park officials often guilty of laying the groundwork for park vandalism? Think about it.

2--Listen to the land. Before putting your pencil to paper, get to know the land you are working with. If it is a wilderness or forest land, sleep with it. Know every tree, rock outcropping, drainage channel, and view by heart. Know the soil, rainfall, vegetation, and compaction and erosion potential. Identify views, amenities, and features on a base map and superimpose all elements of importance until the usable landforms stand out clearly. Also, consider the less obvious concerns, such as noise, wind, light patterns from passing vehicles, etc.

3--Listen to the people. When was the last time you went out into the park and talked to the people using it? There may be a few of you who do this routinely, but I doubt it. And yet, unless we get from behind our desks to talk with men, women, and children deriving benefits from our parks, all our planning and operation philosophy is really theoretical rather than actual. I think you must realize

[1] Reynolds and Associates, Environmental Analysis Foundation, Newport Beach, California.

that the vandal is not just another "turkey" from the city, but a person with needs that are not being satisfied in our parks at the present time. Oh, yes, there are some vandals who just don't know any better or they have destructive tendencies because of a psychological problem. But I'm not really talking about them. I'm talking about the person who vandalizes because he is angry. Angry because he feels that he has been left out. There is much that you and I can do, not just to hear what people think about our parks, but to listen to their needs. There is a difference. Hearing is merely the physical act of receiving a sound, whereas listening implies understanding.

4--Kick your planner. Be sure your planner is awake--get him out of his office--before, during, and after the park project. Encourage him to try new communication techniques and workshop processes. Send him to conferences and allow him to work with other professionals. Be sure the planner knows all the operation and maintenance problems. Have him spend a week with a crew, or find ways he can improve operations through design. But most important, be sure he is awake--and learning everything he can about your agency and its problems. The planner is the man in the middle. He should be getting feedback from the bottom up and from the top down. Unless he gets this, he cannot be effective. If you use outside consultants, kick them harder. They need to get more feedback from more people in less time in order for them to offer added value. Don't be afraid to mix outside consultants with staff on a given assignment. The competition and interaction can do wonders for both. Tremendously effective problem solving can be accomplished in short periods of time from this synergism.

5--Throw out the budget. "Cheap is the vandal's meat." The budget--often broken apart and allocated before any of the above steps have been taken--becomes a catalyst to vandalism. First, relate what you found out from the land to the needs of the user. See if the site is adequate, whether boundaries need adjustment, whether the capacity to accommodate exists. If the answers are affirmative, then prepare at least three to five alternative concepts, any of which could be a solution. A word of caution: don't confuse variations on a theme with alternatives.

At this point, you should prepare a composite plan or synthesis. Evolve it using the workshop planning process. Based on this "best" concept, now do a cost estimate and budget related to the life of the facility.

6--Burn your standards. Most equipment standards and most catalogs are out of date. The equipment is static, often understressed, and has limited life. I am disheartened at the trend toward fiberglass equipment. My experience has shown this material to be highly susceptible to early aging and changes. Avoid it wherever possible, and instead build stronger and longer-lasting facilities--better culverts, restrooms, and community buildings. Don't hesitate to be a pioneer. I say this because in all sincerity I feel that is is up to the planner and designer to be the source of new ideas. We should be the ones telling the manufacturers what we need and what we want for long-range park usage. The manufacturer and the workmen all look to the designer for guidance. If we don't provide this, then we deserve the second-rate equipment and materials we now have.

7--Design for the centuries (not 1980). So many things seem to have a lifespan related to man's own; not so a park. Parks remain--they often last for centuries, and should. So will our public lands and remote areas, if history is correct.

The question is what do we do with a parcel of land that will be here for centuries, but which is part of a 1980 recreation plan. Well, I believe we must design for the longer period of time. We need heavier construction; greater strength, durability, and usability; and less intensive use, but more durable elements. We also need more sites with fewer, better placed, and more durable picnic and camping spaces. Each planner should ask himself what his solution will be like in 20 to 50 years rather than 5 years from the date of completion.

So what about materials? Vandals destroy everything in sight if a park is not policed.

In designing for the next century, we recommend a return to stone and other masonry, reinforced concrete, and hardwoods, as well as wood-imprinted concrete. We suggest fewer man-made elements, not more. Fewer signs, but better detailed; fewer log curbs, and no fiberglass any place. We suggest reinforced concrete restrooms built into the hillside--opening only on one side--and that side to public view.

What about policing at night? We suggest that County government, for example, use County parks for fire station sites, particularly when gated park entries are impractical. This would place people and light within the park 24 hours a day. It is also a cost-effective decision, in that fire stations are otherwise placed on expensive land, purchased for a single use. Fire stations themselves can then be multi-purpose park structures and enclose a park office, public restrooms, library, post

office, etc. We can no longer afford single-use, single-agency, single-purpose thinking. For multi-purpose structures we can afford vandal-resistant materials. Similarly, parking and other facilities should serve multiple users.

I think we are making unhappy users, and hence more vandals, because of the current trend to a planning policy of keeping campers close together, with spaces more compact for control and less damage to the forest area. Theoretically, it provides more safety, less policing, etc. This to me is a formula for disaster. Too many people, overuse, small spaces, too many controls, fiberglass benches, catalog fireplaces, and regimentation cause stress, just as too much noise, light, smoke, dust, etc. result in complaints.

A low-density campground, open and well spaced, with free areas and fewer controls will result in a better long-ranged facility--and allow flexibility for future adjustments.

I believe strongly that overcrowding in forest and park campgrounds is the cause of the worst vandalism of all--penetration and destruction of the "back country" by those still seeking to get away for a while. We must provide that escape through planning present spaces better.

8--Experience the errors. One serious mistake we designers make is that we do not go back and experience our errors. We also make a lot of unnecessary excuses. We're human and we are learning as we go. We become accessories to vandalism, however, by not revisiting the work that we have designed. We should return to the park and actually camp out. Mingle with the users. Observe. Ask questions. Certainly the users will appreciate the expressed interest. Besides, we may learn something.

9--Correct your problems--be innovative. Once problems and errors (new and old) have been identified, be aggressive and innovative in solving them. Don't go on the premise, "Well, we missed on that one; we'll not do the same thing next time," and then leave the problems unresolved. Instead, let me tell you what I think is an innovative approach that involves budgeting for innovation.

How can you innovate? By borrowing a technique used in progressive industrial organizations. They too set up budgets for capital investment, operation, maintenance, etc. But they go one step further. They set aside funds for cost-effective design research. We can use the same technique, but with a minor variation. Instead of each individual city or county bearing the total cost of this program, agencies and counties should get together with others having common needs. Set up a pool of funds for test sites and learning workshops.

10--Communicate through graphics. Last, but extremely important--communicate informally and concisely through graphics. Using pages and placards full of rules summarized in penalties is offensive communication. One would not do that to a guest in his home. I advocate simple, clear, friendly graphics that exude a welcome. Remember, the user still feels the pinch of financing public works, so he views public land as "his" space. This should be emphasized in all agency policies. In fact, if the user realizes he paid for it, he may respect it more. To be greeted with a penalty clause at the front door and rules of use seems to be poor public relations. Admittedly, this view is oversimplified, but the message given the public is extremely important; and it is often the very first impression received by the park user. Funds spent on professional graphics, concepts, and communication techniques are usually not wasted--nor is the time spent on a warm welcome.

SUMMARY

We planners are partly responsible for vandalism--and vandals are people, users whose needs are not met.

Decreased vandalism will result from providing facilities that are rugged--yet satisfy all age levels in a friendly, uncrowded atmosphere.

Facilities must relate to the site in a functional yet sensitive manner, with an understanding of the holding capacity of the site.

Budgets and standards need to change in their relative importance, and research funds must be used in case studies.

Overuse is an extreme threat in the future, and crowding will cause stress and result in greater problems than can be easily solved.

And last, each planner has many choices to make, and lots of room for growth to improve his designs--it's a much broader question than new coatings and finishes--it's prevention through process-oriented design...and most eyes are on the planner.

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SOCIOLOGY OF VANDALISM

Photo: East Bay Regional Park District

Research to determine the kinds of recreational opportunities desired by different groups can help to ensure that varying cultural needs are satisfied.

Vandals Aren't All Bad

Michael L. Williams[1]

Vandalism is one of many diverse activities in the broad category of criminal behavior. For sociological analysis, then, both criminal behavior and vandalism must be defined.

Any behavior in violation of the criminal law is criminal behavior. If there is no statute covering such behavior, there can be, given our constitution, no violation of the criminal law. Of course, practically speaking, matching statutes with concrete behavior is not always a simple task. However, that is not our problem.

Vandalism is somewhat more difficult to define. If we turn to the penal code we find that there is no such offense as "vandalism," though the definition of "malicious mischief" closely corresponds to a commonsense definition of vandalism. "Malicious mischief" is, simply, the malicious or intentional injury to or destruction of real or personal property by someone other than the owner. The law, though, tells us nothing about how and why people engage in acts of malicious mischief or vandalism.

There are several related issues here:

1. Acts of vandalism do not differ qualitatively from other types of human behavior.

2. Acts of vandalism occur in the course of or as the results of social interaction.

3. The creation of laws and administrative rules (as in national, state, and local parks and reereation areas) serves to focus both official and public attention on the vandalism problem.

The first point, then, is that acts of vandalism do not differ qualitatively from other types of human behavior. Emile Durkheim,[2] an early but influential sociologist, noted that crime was a normal feature of a complex society. Crime, moveover, had a positive function in that detection and punishment of violators served to reinforce collective belief in the social system and its values.

Although it is difficult to condone carving one's initials on a picnic table, spray-painting a rock or tree, plugging up the plumbing in a restroom, or dumping over trash cans, we nonetheless enshrine similar assaults on our environment when perpetrated by a historical figure or an ancient unknown, or when the act itself reinforces a collective or national consciousness. Thus, when an enterprising hotel proprietor pushed some burning embers over the top of Glacier Point in Yosemite, a tradition was begun that lasted over seventy-five years and was halted not because it was wrong in principle, but because it was causing a massive traffic jam and law enforcement problems. In the same National Park, someone actually carved a tunnel through a Giant Sequoia. Until the tree fell down a few years ago, this was another highlight of a trip to Yosemite. Today we attempt to preserve the acts of Indians who defaced the walls of caves hundreds of years ago, an act that, if done today in the same location, would result in prosecution if the culprit could be caught. Finally, let us not forget the grandest act of all. First conceived in the early 1920's, Mount Rushmore, with the faces of Washington, Lincoln, Jefferson, and Roosevelt, is undoubtedly one of the most revered examples of the sanctioned destruction of the public domain.

The question, then, is what distinguishes these acts from the senseless destruction and defacement normally associated with vandalism? The only response that I can defend is that none of the last described acts were violations of the law at the time they were committed. It should be noted that the exact nature of the act did not go unnoticed by the proponents of the "creation of a symbol of the national spirit." For work to go ahead on Mount Rushmore, both State and Federal legislation had to be enacted. Otherwise, by law the sculpting would have constituted the intentional destruction and defacement of the

1 Assistant Professor, Department of Sociology, University of Maine, Portland-Gorham.

2 Durkheim, Emile
1933.. On the division of labor in society. Macmillan.
1938. The rules of the sociological method. Free Press, New York.

natural environment. Each of these acts, though, were completely legal at the time they were actually undertaken.

Yet if I maintain that the only distinction between vandalism and nonvandalism is that the destruction or defacement of property is illegal, then I am asserting that destroying a restroom is qualitatively the same as destroying "an old park headquarters" to make way for the new, or that carving one's initials on a tree is merely a small-scale version of what logging operations do to forests, namely deface and/or destroy. Clearly there is a difference, albeit a culturally defined difference. Namely, one class of activity is of direct economic importance and the other is not. Another way of stating the distinction is that one class of activity has utility but the other does not. The reason the distinction is merely cultural is that our culture readily provides us with a rationale for the destruction that necessarily accompanies logging operations, whereas we are usually hard put to discover logical reasons for the seemingly wanton destruction of property that we call vandalism.

Recently, however, sociologists[3] have noted, based on limited data, that such "senseless" and apparently nonrational vandalism is, from the point of view of the perpetrator, a rational and instrumental act. To return to the main point then: vandalism is not qualitatively different from other types of social action. It is clear from my perspective that there are many, many examples of destructive activity which differ from those acts we refer to as vandalism only in that they are not violations of the law. And if the law is the only distinction one can make, then it is likely that from time to time the law will be violated.

The second point I would like to address is the assertion that acts of vandalism occur in the course of social interaction. Wade[3] has similarly noted, "...In actuality much property destruction by juveniles is a spontaneous outgrowth of group interaction having social, cultural and ecological determinants." Because vandals are seldom apprehended in the act, it is easy to suppose that the culprit was acting as an individual--a supposition which, of course, reduces the visibility of social interaction. However, the research of Wade and Stanley Cohen[3] indicates that "vandalism is almost always a group rather than an individual offense."

It is this point, that vandalism most often is a group offense and occurs as the result of interaction between group members, that remains remarkably unexplored by sociologists.[4] By illustrating the interaction which accompanies acts of vandalism, the similarity between vandalism and other action, such as play, will be illustrated as well. Two examples immediately come to mind where the play situation merges with activity that could be defined as vandalism.

The first was provided by a colleague. When he was a boy back in Minnesota he went hunting with a friend. On the day in question, though, game was not to be found. Not a shot was fired until one youth challenged the other, "Bet you can't hit that glass thing up there." The other boy could, and the rest of the day was spent shooting glass insulators off power poles.

The other case that comes to mind dates from my own boyhood. Once, I and the other neighborhood children of the postwar baby boom were engaged in our usual after-school dirt clod battle. This afternoon, though, we drifted into an orange grove. As might be expected, dirt clods quickly gave way to oranges as symbolic missiles of destruction. It was not until a mother, unfortunately mine, looking for her wayward son, discovered the battle that it was brought to a conclusion.

In both examples the destruction which occurred was largely incidental to the act. Insulators were shot as demonstrations of marksmanship rather than objects of destruction. Oranges served as missiles rather than objects to be destroyed. In addition, these particular acts were not solitary but occurred

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3 Clinard, Marshall B., and Andrew L. Wade
1958. Toward the delineation of vandalism as a sub-type in juvenile delinquency. *J. Crim. Law, Criminol. and Police Sci.* 48:493-499.
Cohen, Albert
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4 Instead they have focused on the epidemiology of vandalism. Much has been written about the sociocultural variables associated with vandalism but little about the act of vandalism itself. See:
Bates, William, and Thomas McJunkins
1962. Vandalism and status differences. *Pac. Socio. Rev.* 2:89-92.

in the course of interaction between two or more persons. By interaction I do not mean to infer that extensive discussion must preface any act of vandalism. Interaction simply means the communication of information. Thus, in the first case the dare or "bet" constitutes a tentative proposal for action. The actual shooting of the insulator, then, reaffirms the proposal as being appropriate. Similarly, throwing an orange can notify other participants of a new missile. Again the response to the initiation of the act of vandalism reaffirms the behavior as appropriate in that situation.

One need not propose, then, that juveniles who engage in such behavior are deficiently socialized or are bad kids. In fact, if confronted with examples of good behavior and bad, I would expect the children would know the difference and would choose to act out "good" behavior over "bad," at least in the abstract. But the point is that in the real, concrete situations children and adults must confront, "good" and "bad" are seldom so clearly distinguishable.

Neither should the above examples be taken to indicate that only juveniles engage in acts of vandalism. Adults have been known to carve their initials in tables, tear limbs off trees for campfire wood, and drive four-wheel-drive vehicles in a manner which is destructive to terrain. Each act, in its context, can be normalized, and, like the acts of juveniles, usually occurs as the result of interaction with others. Thus, when on patrol with a Deputy Sheriff I observed the following incident:

> A four-wheel-drive pickup with roll bars and extra lights was stuck in the middle of a large, muddy bog in a field. When the Deputy asked what happened, the owner said, "We were just driving around and he said, (pointing to another man) 'Let's go through that field.' So I did." When the Deputy said, "Don't you know this is private property?" the man lamely said, "I didn't think it would hurt anything."

Though vandalism is frequently normal activity or an extension of normal activity, play, and though it is usually (according to the limited research) a group rather than a solitary phenomenon, the possibility remains that it is solitary. Thus, property may be destroyed or defaced as a form of retaliation or retribution, especially when a person perceives that he or she is impotent to bring about a legitimate solution to a problem or conflict with another. The person who plans and is bent on such an act is, of course, difficult to foil because (1) he develops a plan, and (2) he perceives he has a moral or just reason for his indignation. Fired employees or persons prevented from entering a park (for whatever reasons) may perceive that they have been treated unfairly and seek to retaliate for the wrong they have suffered. Though this type of act seems to be qualitatively different from those which occur as an extension of play, there is no need to assume that it cannot be conceived of as normal or that it occurs in the absence of interaction with others. First, many people retaliate every day in little ways against persons (husbands, wives, or close friends, etc.) who have "done them wrong." So the mere act of retaliation is not, intrinsically, abnormal. Likewise, because the actual retaliatory act may be the work of a solitary individual, there is no reason to assume that a good deal of interaction did not precede it. It is easy to conceive of a situation in which others convince a person that he has been unjustly treated and provide him with a course of action.

It has been asserted that play and retaliatory acts are normal aspects of everyday life. In addition, vandalism occurs as the result of interaction between two or more individuals. When they jointly engage in acts of vandalism, the interaction is fairly obvious. However, even solitary acts of vandalism are probably preceded by interaction. In short, it appears that when one focuses on the actual act of vandalism and the interaction which precedes such acts rather than the products of vandalism, apparently senseless destruction is not different from any other social action.

This assertion returns our focus to administrative rules and laws which serve to distinguish vandalism from other categories of social action. Earlier I asserted that "the creation of laws and administrative rules serves to focus both official and public attention on the vandalism problem." They do so in two ways. For example, a few years ago a back-country survey in Yosemite noted that there were literally hundreds of fire rings around one of the Cathedral Lakes. This and similar findings led to the development of a policy which restricts the use of campfires in the back country to a limited number of campsites. In addition, an attempt was made to break up many fire rings and a policy was implemented which allowed fires only in previously constructed fire rings.

This example illustrates that a problem was recognized that resulted from legitimate but unwise or at least unesthetic actions of previous backpackers and horsepackers. Creation of the rules which restricted locations where campfires could be built and specified that they were to be built only in previously constructed fire rings constitutes an <u>ex post</u>

acto recognition that such acts constitute andalism in the form of defacing the natural nvironment. These rules then call attention o the vandalism problem. But they do more. o the extent that the locations of existing ire rings and legitimate locations for campires is known to officials, construction of ampfires in other than prescribed locations onstitutes a persistent vandalism problem hat could not exist before the enactment of he rules. A second consequence of the new ules certainly was not intended by park offiials but occurs nevertheless. Because there re relatively few locations where campfires re allowed, backpackers and horsepackers tend o congregate in those locations. Firewood oon becomes scarce and campers, expecting to ave a fire but frustrated in their search for uel, frequently lift their eyes skyward to till standing trees, both living and dead, as ources of fuel. As a result of this, I have een a magnificent, knarled old snag reduced o little more than a great stump.

Thus, there are two ways in which the creation of rules and laws in turn creates and focuses attention on vandalism. The first is simply by labeling previously legitimate behaviors as rule violations--vandalism; the second is by placing those people who attempt to act in compliance with certain laws and rules in a situation that is conducive to their violation of other laws and rules.

It should be clear that acts of vandalism cannot be easily controlled by those who are handed this task. Yet we can take a cue from the previous discussion to find a possilbe solution.

Consequences

The consequence of the point made that vandalism is normal or, at least, an outgrowth of normal, legitimate activity is that we can expect that, despite efforts to control or eliminate vandalism, it will persist.

The second point, that vandalism occurs in the course of or as a result of social interaction, provides some hope for limited control of the vandalism problem. The solution lies in an attempt to gain control or interaction settings.

Many methods may be utilized. Some, such as education, are not directly related to the actual situations in which vandalism is likely to occur. Other methods, such as design, may be utilized to affect physical settings in such a way as to minimize vandalism. Proactive methods--programed activity--may be employed to channel park and recreation area users into nondestructive courses of action or even behaviors which benefit the recreational setting. Finally, reactive methods in the form of a traditional law-enforcement program, may, from time to time, be the only solution to acute vandalism problems.

Finally, as a consequence of the third point, that the creation of laws and administration rules serves to focus both official and public attention on the vandalism problem, it becomes apparent that officials should attempt to formulate the expected results of any proposed rule or policy. They might then avoid the predicament of the doctor who had to say, "The operation was a success but the patient died." In other words, the proposals for controlling interaction settings must be closely scrutinized for unintended consequences and the effects of such consequences should be closely evaluated. It seems that most people want to obey rules, but these are not always the rules you or I want them to obey; sometimes they are the rules of their peers, friends, or some other reference group. It is up to those to whom our parks and recreation facilities are entrusted to see that the rules conducive to preservation and protection are relevant above all others when the public is at play.

A final note of pessimism is in order, though. Do not forget that while camped near Glacier Point in Yosemite, John Muir, the man perhaps most commonly associated with the conservation and preservation of our natural heritage, once set fire to a large fir tree in the middle of a meadow. His audience, then President of the United States Theodore Roosevelt, the president instrumental in creating more National Park and Forest land than all of the presidents who preceded him shouted, "Bully, there's a candle that took five hundred years to make." Though times change, almost all members of society will on occasion find themselves in a setting in which destruction, or a spectacular display, or leaving one's mark, seems to be the most appropriate activity at that time. The problem then is not merely, "Can we eliminate or at least control vandalism?" but "Can we do so without eliminating the essence of the recreational environment we seek?"

The Message of Vandalism

Arthur W. Magill[1]

The common perception of vandalism is of a uniformly wanton, meaningless, and senseless crime. When motives for such behavior are not readily apparent, we are quick to call it motiveless and label it as deviant. Those who are wronged or harmed by vandalous behavior are likely to consider the deviant as sick or defective or the product of his environment (Armstrong and Wilson 1973). But, are persons who commit vandalism really afflicted with a pathology, are they defective people, and how much does their physical environment determine their behavior?

In the musical play "Camelot," knights cry "Fie on goodness! Fie!" and long for war, some killing, and pillage to brighten their lives. Isn't their rebellion closely akin to that of the bored youths of a low-income housing project? Can we see in the knights, those "good citizens" of another time, the counterparts of today's vandals? And can we really say that the acts of either group are without cause--motiveless?

Social psychologist Stanley Cohen (1973) has said that deviance is a social phenomenon. It commences when vandalous acts become visible and create public awareness. Various individuals and groups then draw additional attention to acts they regard as threatening to their own system of moral values. When public concern and support is stimulated through the appeals to commonly held beliefs of causation, such as immorality or emotional disturbance, those responsible for vandalous acts can be labeled as deviants. At this point, a social problem is recognized and control efforts begin. The likelihood exists, however, that the "deviants" may have been condemned on the basis of unfounded beliefs; there may be no attempt to help them by identifying the meaning behind their acts.

But just what is behind vandalism? Physical and mental defects; broken homes; public indifference; and failure of parents, schools, and our social system to teach responsibility and morality have been specified by the Federal Bureau of Investigation as contributing to vandalism (Bennett 1969). Seeing human needs as the basis of the problem, Cohen (1973) suggested the need to get money, to advance a personal objective, to express social protest, to gain revenge for some imagined or real wrong, to gain release for hatred, and, in children, to express curiosity and competition through spontaneous play.

Our willingness to write off vandalism as senseless and wanton and to apprehend and punish vandals should be replaced by the desire to identify motives and modify stimuli. Unfortunately, if we learn that vandalism on wildlands is related to problems of cities--pollution, unemployment, poor housing, and other inequities--we may respond by "externalizing" vandalism--we may see it as outside our area of influence. Greenberg (1974) found, for example, that school administrators chose to externalize vandalism because they believed its source was outside of the school system and not their problem. Resource managers could easily take such a course, but they would then face the need for frequent police action, frequent replacement of facilities, and constant concern in facilities design to inhibit acts of vandalism. Greenberg also found, however, that school efforts to maximize security and harden facilities were doomed to failure. The evidence clearly points to the need to identify motives and remedy problems at their source.

ENCOURAGEMENT TO VANDALISM

Despite some evidence to the contrary (Clark 1971), studies have found the majority of vandalism to be caused by youth, generally between 13 and 21 years of age (Bennett 1969, Armstrong and Wilson 1973). This kind of information tends to make adults regard any gathering of teenagers with suspicion. In addition, some adults regard young people as a kind of "nonpeople" or "not-yet-people," who are bothersome and have no feelings. Under these conditions, the adults might be seen as the true vandals, or more precisely, contributors to vandalism.

Goldmeir (1974) found that parents tend to interfere with the squabbles of their

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children or to object to activities, innocent in themselves, which the parents find annoying. Consequently, simple conflicts of interest may grow out of proportion and lead to vandalous acts by the children aimed at "getting back" at those who originally interfered or complained of their behavior. Calling in the police only tends to intensify the problem; a nonthreatening third-party mediator is really needed.

A possibly more serious parent-child problem develops when the child acts out the parents' deviant fantasies (Ward 1973). For example, if parents are unemployed and housing is poor, there may be continual fights between family members, and complaints and even threats may be directed toward the social system. Children listen, observe, and then vandalize facilities that are symbolic of the sources of their parents' problems. Again, arresting and punishing the children does not reach the cause of the problem. The adult behavior and its causes are the problems that need solving.

Let's briefly consider why police action is not generally acceptable. In Scotland (where police may not differ appreciably from our own), researchers (Armstrong and Wilson 1973) found that vandalism and delinquency were developed by police action. The police tended to harass teenagers when they were not causing trouble until the youngsters decided to give them reasons for "busting" them. A library search of newspapers would undoubtedly reveal numerous examples of similar police-youth conflicts.

Planners, developers, architects, and other public officials may also be considered "vandals" as a consequence of poor design, failure to recognize social or cultural needs, or indecision in urban development or redevelopment planning (Ward 1973). Robert Sommer (1972) indicated that good design should go beyond mere physical structure and should consider social consequences. Poorly designed buildings and projects have nearly three times the crime rate of adjacent well-designed projects, even when densities and social characteristics of residents are identical (Newman 1972). It may follow that if good building design results in lower crime, then good facility layout design should reduce vandalism in parks and other recreation areas. Just "hardening" facilities, though it does not stop vandalism, may slow it, however. Similarly, prompt repair or replacement when damage does occur, can reduce repetition (Ward 1973). For example, Anselmo Lewis, retired ranger on the Mt. Baldy District of the Angeles National Forest, discovered that people were digging up trees and shrubs planted to beautify recreation areas. Frustrating as it was, he replanted each time until the plants were finally established.

Design to serve the social and cultural needs of people is far more important than design to gain the plaudits of one's peers. The first should produce a more livable environment which is less likely to breed vandalism; the second may only serve the designer's ego and perpetuate public ills, including vandalism. In another study, British investigators (Ward 1973) found that residents liked historic old buildings which contributed an appealing character to various districts. Time can be an enemy of such structures if administrators allow them to stand unrepaired or unreplaced, because they soon become targets for vandalism. Vandalous acts may be assured, however, if historic structures are replaced without replicating culturally accepted styles. Neglect and indecision by administrators may be termed bureaucratic vandalism; it may stimulate acts of traditional vandalism by residents (Cruickshank 1973).

OPPORTUNITIES FOR CONTROL

Various means for controlling vandalism have been suggested, and some of the proposed solutions have actually worked, though usually for specific problems. There does not appear to be any universal remedy, but some approaches seem promising. Increasing the visibility of vandals, developing means for two-way communication, and getting people involved in community programs are among the many techniques that may lead toward more universally successful controls, possibly with decreasing need for punishment.

Increasing Visibility

Oscar Newman (1972) claimed the battle against crime can only be won when people stop trying to protect themselves individually and unite as a community. He approached the problem through design; design that makes the criminal or any intruder cognizant of his visibility and the resident capable of recognizing and repelling intruders. It is design that binds individuals into a defensible community; he calls it "defensible space." The key to his design is improved surveillance. Buildings constructed in new housing projects are arranged to be intervisible. Apartment windows and entry ways are located to make grounds, entries and halls easy to observe. Landscaping is pleasing but does not provide good hiding places. Buildings and external structures, such as fences, are arranged to separate public from semipublic spaces. The entire design works to build a sense of community. It not only makes the area easily observable but encourages neighbor familiarity, thereby assuring that unknown individuals or

undesirable activities are quickly recognized and controlled.

Newman's approach suggests that recreational areas may be designed to establish a "temporary sense of community" among users, allowing them to respond to depreciative behavior effectively yet without jeopardizing anyone's personal safety. The success of such a design requires interaction among recreationists. Several years ago such interaction may not have occured, but today evidence indicates a new breed of wildland user; one who is socially oriented and therefore establishes new friendships during his vacation (Clark and others 1971). If developed recreation areas are patronized by such visitors, then designing defensible spaces for their use may provide the proper mix of ingredients to increase surveillance and reduce vandalism.

Good design, design that is not only defensible but which effectively serves real human needs, should invite greater use of areas now going unused. Increased use, in itself, may provide a deterrent to vandalism. For example, New York's Central Park has been known for its high occurrence of serious crime. In recent years public use was increased because city authorities offered new and interesting programs and activities. The resultant large crowds provided a greater amount of defensible space--defensible because the greater numbers of users made more park area visible. Criminal elements soon recognized the park was no longer an "unclaimed" space, but a public property on which they were now in jeopardy. Crime in Central Park has decreased[2] and increasing use is recognized as a successful technique for making parks and other areas safe for public use (Gold 1972, Ward 1973).

Listening and Transmitting

Failure to communicate may be a basic problem for both the victim and the vandal. Stanley Cohen (1973) said, "Vandalism is a solution...ugly and incoherent...difficult to explain...and it will continue to be used until society gets the message." The deviant is transmitting but we are not listening, and we are also transmitting, but because we do not listen, we do not know what messages to send.

What are some of the messages expressed by deviant behavior? Aldo Leopold (1966) defined an ethic in two ways. In ecological terms, he said, an ethic is "a limitation on freedom of action in the struggle for existence," and in philosolhical terms it is "a differentiation of social from anti-social conduct." Possibly, the vandal's "unrecognized cause" or "anti-social act" is merely his expression of <u>disrespect</u> for limitations on his freedom of action imposed by people with a different ethic. His action may have nothing to do with disrespect for the environment, as some believe it does, but it may be a way of "getting at" those who violate the deviant's perceived rights or ethics. Thus, when tables, water systems, barriers, and toilets are destroyed in a campground, resource managers might regard this as a message announcing that somebody feels his rights have been violated. It may be advisable for managers to learn to listen, to identify causes, to examine rules and restrictions, and to change some rules, or to explain why other rules are needed. If the first two of these goals can be achieved, managers may finally "get the message." However, if changing the rules and educating the users are necessary, then managers must also learn how to send their messages effectively.

Effective communication with the public poses a problem for resource agencies. Recently, Ross and Moeller (1974) found that campers on the Allegheny National Forest were not well informed about camping rules. The least informed groups were adolescents, first-time campers, nonlocal users, and tent campers. Messages needed general improvement and required a positive tone. In Colorado, a study of the effectiveness of a wilderness permit information program showed that newspapers and television reached a large number of people, but that few of these people were wilderness users (Fazio and Gilbert 1974). One study conducted by a State agency and two studies by Federal agencies found that despite agency programs to inform campers about where to camp or about campsite reservation systems, most had obtained the information from their friends (Taylor and Knudson 1972, USDI National Park Service 1974, Magill 1976). To reach the public, the messages resource managers send must be more attention-getting, must be clearly written and precisely directed toward well-identified audiences, must avoid irrelevant attempts at regulation, and must recognize real human needs.

Getting People Involved

Vandalism might be regarded both as a symptom of illness in a segment of our society, and an effort by the afflicted segment to cure itself through the expression of hostility, frustration, and helplessness. Psychiatrist Matthew Dumont (1968) proposed this symptomatic approach for examining the ills of cities. Dumont also enumerates people's basic need for a stimulating environment, a feeling of personal pride of self-esteem, a sense of community, and a sense of control over their environment. When basic needs are not supplied in the ghettos, efforts to supply them assume the symptomatic form of riots.

[2]Personal communication with Charles Lewis, Horticulturist, Morton Arboretum, Lisle, Illinois.

Vandalism may merely be a less violent symptom of the same pathology expressed with less risk of apprehension or injury. Schools may also contribute to the illness, especially if they are meaningless to students who see themselves trapped by training that leads to futureless jobs and no chance to escape poverty (Cohen 1973).

Horticulturist Charles Lewis (1973) described a program that seemed to successfully rekindle stimulation, self-esteem, sense of community, and environmental mastery in residents of a very large housing project, where crime, including vandalism, was high. The New York Housing Authority sponsored a gardening contest designed to encourage tenant participation with minimal guidance. Remarkably, most residents of the project got involved and the results were heartening! Not only were beautiful gardens produced, but streets were cleaned and buildings were painted. The entire neighborhood assumed a new look, and most important, vandalism decreased! The gardens survived because the residents could identify the vandals and gave them the job of guarding the plants!

The same technique proved effective for stopping littering and other undesirable acts by a group of youths at a recreation area in a high-income California community (personal communication with Michael Halloran).[3] A few of the suspected teenagers were hired to clean the grounds, and the problem soon disappeared.

The basic human needs of people in cities may also influence the management of recreation areas. Speaking about planning for municipal, state, and national recreation areas, Lieberman (1970) claimed such areas may act as therapeutic environments where city dwellers can receive fresh stimulation and regain some sense of control over their environment. But, the resource manager needs to be aware that some urbanites may bring with them the frustrations spawned in a repressive environment. Their desire to achieve stimulation, self-esteem, and environmental mastery may not tolerate the unexpected and seemingly irrelevant regulations so important to the managers. The unanswered question is, how can resource managers get recreationists involved, thereby preventing depreciative behavior?

Another way to achieve involvement is suggested by resource agency use of public hearings to feel the pulse of concerned citizens on sensitive issues. The same technique may help to identify site and facility designs that most nearly satisfy the users' needs, or to indicate which regulations are irrelevant and possibly need to be changed or deleted. It is quite unlikely, however, that public hearings will stimulate responses from persons who themselves show depreciative behavior, especially those whose frustrations are the product of some institution other than a resource agency. The observational techniques Robert Sommer (1972) suggested for identifying relevant information for designing buildings may prove useful for designing recreational facilities and regulations. The technique requires the involvement of managers rather than recreationists. The user's opinion is expressed only by his behavior, which is observed and recorded. Thus, use or misuse and compliance or definance are the criteria for site, facility, and regulation design. Unfortunately, the observational approach doesn't get to the heart of depreciative behavior. As previously mentioned, the source of vandalism is likely to be outside of the forest, but ignoring or externalizing it will not solve the problem. It may be necessary for resource managers to work through State and Federal legislatures to provide city officials with the kind of support essential for correcting the social ills of our society.

A universal solution for stopping vandalism has obviously not been revealed in this discussion, nor does a solution appear to be on the horizon. Considerable research is needed to develop and test the few approaches discussed. Possibly the greatest advantage of meeting to evaluate serious problems may be the opportunity to expose myths and stimulate new ideas. The knights of Camelot who cried "Fie on goodness," appeared to be a wild lot, not unlike the "hooligans" who ravage our cities and recreation areas. Yet, despite our wars and apparently increasing crime rates, perhaps we should take heart from the words of Robert Ardrey (1961)--"The miracle of man is not how far he has sunk but how magnificently he has risen." If we consider the premise that man descended from a killer ape, then possibly our many efforts to achieve peace may signify the hope for achieving victory over crime.

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[3]Personal communication with Michael Halloran, Director of Pupil Services, San Ramon Valley Unified School District, Danville, California.

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A Psychoanalytic View of Vandalism

Robert J. Sokol[1]

The subject of vandalism is so broad and includes so many different types and degrees, motivations and methods, that almost every aspect of human and social behavior is encompassed. There is no question of the tremendously increasing cost--financial as well as sociological. Historians will trace its antecedents in history. Socialists and psychologists will focus on the societal roots and the sociologic changes that produce and foster the

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destruction and outpouring of aggression. Their contributions may well lead to an understanding of the broad psychosocial forces and the societal changes that will be necessary for prevention.

I am a different bird--not in anyway better, but different. I am a psychiatrist and psychoanalyst. My concern is with what goes on between the ears of any one individual--what goes on between these ears not only at a level of awareness, that is, consciousness, but at a deeper level as well, outside the level of awareness, that is, the unconscious. What makes an individual destroy and deface in a wanton fashion? We are all aware of the cultural change, the changing social mores, the problems of the disadvantaged, the ghettos, TV violence, drugs, etc. But why does one frustrated school kid pout and another destroy? Why--and how to stop it? A complex problem indeed.

Since, as I mentioned, I wear several hats--as physician, psychiatrist, and a psychoanalyst--I'd like to approach the problem of vandalism as I would any medical problem. I don't intend to convey that this is any better approach than a moral, legal, or sociologic one--but only that it may be different and in its difference, additive to the others.

From my vantage point, vandalism, then, is the symptom, the endpoint of a disruptive behavior. As for any symptom, although the final results are similar, the causative factors may be considerably different. Yellow jaundice may result from liver disease and the backing up of bile products into the blood. The same symptom may result from a blood disease with the breakdown of red blood cells. The causes may be cancer, alcohol, certain types of anemia, or the Anopheles mosquito and malaria--but all result in the same symptom. So, the first thing is to attempt a classification of the different psychological determinants which may result in vandalism. If you try to treat the jaundice from alcoholism as you would that from malaria, you're going to have a large number of very dead patients.

I have searched the literature in vain for a classification of vandalism from this point of view, so what follows is an initial attempt:

1. Territorial Imperative--The term derives from observations by Ardrey and others of animal behavior, namely, that all animals attempt to delimit their boundaries--their "turf" in modern venacular. This might be called the "lifting the leg" or the "Kilroy" syndrome. In its grossest fashion, it can be seen in gang behavior and the various markings on buildings in our cities. In more subtle forms--the carving on trees, writing in men's rooms, etc.--it may be a way of relieving the tension of being in a strange area and a distorted attempt to maintain psychological continuity in a strange place, perhaps a subtle derivative of the homesickness of youth. The point here is that hostility or aggression may not be a major motivational force.

2. Frustration-Aggression Motivation--In this broad category, a sense of frustration, which is really a combination of helplessness and anger, acquires an aggressive release. It is important that there is a displacement from the original causative object onto a passive recipient object. You get angry at the boss and come home and kick the dog. A child is angry with a teacher (rightly or wrongly) and breaks windows in the school. We see this type of thing normally in children's play--boys smash toy cars together and chortle in glee. When the toy cars become real cars or the house of blocks becomes a school house--then we have troubles. The point is that there is pent-up tension within the person which is relieved by action and destruction. The passive recipient of this behavior, the object--a building or a tree or a car--is not the provocative agent, merely the receptor. Indeed, ask a boy who has broken a window why he did it, and he may well say, "I dunno" or "I didn't think"--unfortunately too often true.

3. Purposeful--political--This is a category of vandalism that unfortunately is on the rise. Witness the bombs, the fires, the "purposeful" destruction for some cause or message. This is not just "letting off steam," but a planned and purposeful act with an ulterior motive.

4. Psychotic Vandalism--This final category is a distinct one that results from what we classically describe as mental illness. Here the violence and vandalism may be random or selective depending on the nature of the illness. The differentiating point is that there is no avowed ulterior motive other than pleasure. The arsonist is one example of a limited psychosis.

These, then, are four categories that I have separated. There may well be others and there is certainly overlapping. But what is the value of this classification--after all shouldn't diagnosis lead to treatment--or at least to avoidance of unnecessary treatment? Here, I think you can direct your treatment attempts to categories 1 and 2. The police will play a major part with category 3, and the mental health professionals with category 4 (once the vandals are apprehended). Of course this statement is an oversimplification; all of us may be involved in different ways with each of these categories.

Before I discuss the "treatment" phase of my medical model, some further diagnostic criteria are necessary. This has to do with the timing and frequency of the vandalism. Is it acute or chronic? Is it a sudden outbreak like an epidemic? Is the rate of increase gradual or rapid? Is the type of vandalism changing? Consideration of each may lead to diagnosis, treatment and, with early diagnosis, prevention becomes more possible. The classic example is a sudden outbreak of vandalism at a school or park--if it is epidemic it always indicates some major dissatisfaction between students and faculty or young people and park administration. Almost always there is some breakdown of communication which may need to be reestablished by a variety of means. In Los Angeles County and elsewhere in the country we have used teams of mental health professionals who have gone into schools as consultants and assisted in the reestablishment (or on some occasions initial establishment) of school-community relations. Could these be useful in parks or other situations?

Now let me put on my other hat, the psychoanalytic one, and get down to some things that go on between the ears, and particularly in the unconscious. I want to emphasize two main points already alluded to--these are (in our terms) object distortion and the phenomenon of transference. I have chosen these two because they are universal; they occur to greater or lesser degree in all of us. The trick to it is, if we are aware of these phenomena then we may be able to anticipate them and take measures to minimize their effects on behavior. I want to emphasize that these are very complex phenomena and this will be only the briefest surface skimming.

In its crudest form, transference means the displacement of feelings or emotions from one person or object to another person or object. In this process the perceptions of current person or object may be distorted in the most subtle or gross fashions. I should mention that this displacement of feelings or emotions, as it occurs in the unconscious, has no relation to real time and indeed often links the past and the present. The most obvious example would be that of a policeman who is the object of fear and hostility even when there is no immediate cause for guilt. He is not being responded to as that individual policeman--who may or may not be a nasty person. You might say he is seen as a representative of a group by whom the person has been threatened in the past. Yet we know that this same type of reaction frequently occurs in those who have had no bad previous experiences with police. In the analyst's office, the unconscious link between the police and the punishing father can often be determined. Mind you, the link, distortion, or misconnection may have no relation to the real father, but only to that aspect of the father that was involved in punishment.

This seemingly esoteric phenomenon has rather important practical ramifications, for the policeman's actual behavior may foster or diminish these kinds of distortions. For example, it is widely known in police circles that involvement in a family dispute can often result in threats or injury to the policeman who intervenes When, as in many newer training programs, the officer can be trained to depart from his usual firm or noncommittal expression--for example, to take off his hat, sit down and ask for a glass of water--the outcome can be materially changed. To put it more succinctly, when the officer can come across as a human being, he diminishes the opportunities to project unfavorable characteristics onto him. To translate this into practical terms for park and recreation area managers--what kind of uniforms should park or school police wear and how should they be trained? Some smaller police departments have experimented with replacing the traditional uniform with blazers--with success. In larger city departments it is often felt that this would dilute police authority to a degree that outweighs the advantages. I suspect they are right. Again, the point is that these solutions must be individually tailored for each specific situation. Attempts to employ a single solution "across the board," though it may be a good idea for a given situation, may well lead to getting a bad name and being discarded.

I have attempted to show how these psychoanalytic principles relate to people. But, how do they apply to things? Is it by accident we call our schools "Alma Mater"? Is it by accident that we call our boats "she"? And does this "accident" result in omnipotent distortions that lead boaters, who are untrained or cannot swim, to take their boats into situations for which they are ill prepared; after all, mother is safe and she will protect us from harm. What about a stately tree--what leads a usually nonviolent person to carve his initials, mutilate it, or even hack it down? Is it a tree he is injuring (in his mind), or is it a symbol of beauty or strength that one envies and must destroy or deface to relieve his envy and sensations of inadequacy? In the simplest terms, is it a phallic symbol?--perhaps, but usually much, much more.

Recently, I was in Yosemite sitting on a bench at the base of Yosemite Falls. Ten feet away a young lady sat on a similar bench carefully carving her initials. My friend berated her and received a defensive, angry, and belligerent response before she left--she was

clearly embarrassed. When I walked over, I noted two old sets of carvings next to where she was "lifting her leg." Did the presence of other carvings unconsciously allow or encourage her activities? Would it be cost-effective to have some kind of removal crew?--I don't know.

Again, are these institutions--our parks, our schools--symbolic of extensions of our families? Then, particularly if they are beautiful and the real families are not, will they become the objects of distortion and envy which will necessitate mutilation to "cut them down to size" so to speak? Now the paradox is that if we can actually link our schools and parks (even, dream of dreams, our cities) to the real family, then the controls of the family setting may be extended to these institutions and protect them from distortion and destruction. These are some of the principles that underlie the concepts of developing community involvement in schools and neighborhood parks.

In closing, I want to emphasize that I have only briefly skimmed some of the very complex phenomena involved in vandalism. Let me merely mention one other, that is, that we all need guidelines. It is only with full maturity that the guidelines of behavior become fully internalized. Thus, during our long (and too often perpetual) periods of immaturity, the firmness, consistency, rationality of our external guidelines--our laws--must be maintained. It is important that a system be developed whereby transgressions of the guidelines are rapidly and appropriately punished. Excessive punishment for a particular crime is as useless as an inadequate reprimand and unsupervised probation. After all, the point is to foster growth and internalization of reasonable and appropriate guidelines so that external force and restrictions become less rather than more necessary. But this involves the whole criminal justice system and will require considerably more study.

Vandalism is a problem of and for society, but is done by individuals or small groups of people. To understand and prevent this problem, it is necessary to understand the forces within the individual. Although broad societal changes are involved, these are dealt with largely through long-term planning and gradual and evolutional processes. It is my firm conviction that by dealing at an individual or small group level, significant changes and inroads can be accomplished, often in a short time period. I should also mention cost effectiveness. Is it more cost effective to replace all the glass windows in a school with high-tensile-strength plastic? Is it more cost effective to develop and maintain a high-level security force at a school or park? Or is it more cost effective to have available a specifically trained mental health consultant, one who is familiar with the situation, to help develop programs or foster communications to avoid or minimize problems? I think the latter may be very cost effective indeed--ask the Sausalito Police Department and many other groups I could name.

Finally, broad programs may be useful, but they will never replace an individualized problem-solving approach. Psychiatrists and psychoanalysts do not have the answers. What we have is a specific vantage point--on individual and group behavior. This vantage point is one of the many that must be included in the planning process if we are to deal effectively with these problems. The various programs I have alluded to should not be taken as direct suggestions. The final solutions must result from your creative thinking.[2]

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Vandalistic Forest Fire Setting

William S. Folkman[1]

VANDALISTIC FOREST FIRES

More than 90 percent of the 100,000 wildland fires in the United States each year owe their origin to man or some agency of man. What percentage of these fires might be classified as vandalism depends on the definition of this imprecise term. Wildfires are started by a variety of people and their motives are even more mixed. Fire-start behavior ranges from the innocent play of a child to the deliberate, premeditated act of an arsonist; from the unthinking carelessness of a novice camper to the compulsive "acting out" of a pathological personality; from the conditioned reflex action of a smoker discarding a match or cigarette butt to the violent expression of a social protester. Activity more typically recognized as vandalistic--the so-called "wanton," "senseless," or "motiveless" setting of brush or grass fires by groups of youths--is a serious problem in some areas, the rural complement of torching palm trees or tossing incendiary material into parked automobiles. The harassment of fire control organizations by malicious setting of fires is not uncommon. It is not unknown for youthful off-duty firemen to annoy their comrades on another shift by setting a series of nuisance fires.

CULTURAL INFLUENCES

Incendiary forest fires are particularly characteristic of the Southern United States. There incendiarism accounts for almost 40 percent of all forest fires, in contrast to 25 percent nationwide. A cultural perspective is helpful to understanding of the practice of "woods burning" in the Southeastern United States, and also sheds light on careless fire starting in the rest of the country. (Culture is used here in a broad sense, for the behavior patterns, attitudes, values, and material objects which men employ in coping with their environment--it is the social, as opposed to the biological, inheritance of a people.) The cultural habits of indifference, carelessness, and insensitivity that lead to our notorious littering behavior must surely extend to the careless way in which fire is handled in our forested areas. Hansbrough (1963) finds considerable evidence that early white settlers in the Southern region adopted the long-standing burning practices of Indians of the area--as a hunting aid, to clear the underbrush so as to facilitate visibility and travel, to increase the growth of preferred plants, and to prepare seedbeds. The settlers soon found additional justifications for burning.

Today, "woods-burning" is still a part of the cultural heritage of the South--despite efforts of professional forest managers to discourage the practice. Welch (1970) found that youths in high fire occurrence areas had absorbed parental attitudes supporting a "burning" culture. In some localities, woods-burning has become a retaliatory weapon. In addition to the traditional reasons for burning, setting fires has become a method for expressing antagonism toward governmental agencies and large timber companies--antagonism developed in large measure from past efforts of these organizations to suppress established customs.[2]

Studies of residents in incendiary "hot spots" (Baird 1965; Bertrand and others 1970; Hansbrough 1961; Jones and others 1965) found the following characteristics noticeable in

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[2]Professional foresters were slow in recognizing the utility of fire as a forest management tool. Carefully prescribed burning for specific management objectives is now generally accepted, but indiscriminate private fire setting is still strongly proscribed.

heads of households: they tend to be older, to have limited education, to be highly localized in their orientation, and to be unemployed or underemployed, retired, or working in unskilled occupations.

Clearly, then, culture strongly determines incendiary behavior in areas of high forest fire risk in the Southern States. The continuing sentiment for burning, along with inadequate understanding of forestry agencies and their work, undoubtedly accounts in large part for the continuing high rates of incendiarism.

In the West, incendiarism contributes to the incidence of forest fires, too, but to a much more limited extent. Generally, starting fires is not supported by the culture, and is considered antisocial, malicious, or pathological. The incendiarism that occurs in the West has a diverse origin, ranging from primarily economic motives to social protest, to classical psychopathology.

Local opinion leaders, sharing many of the same characteristics as the audience to be influenced, have been used successfully in Louisiana and Mississippi in dealing with their incendiary problem.[3] Of special importance in this program were the choice of a "contactor", and the manner in which the message was presented. The contactor's success was found to depend on his acceptance by both the local people and the fire prevention agency. He must be a leader, philosopher, and friend to most of the people in the community and one who inspires rapport and trust. Similarly, messages with negative connotations ("Don't burn the woods") are difficult to sell. Messages oriented toward the recognized needs of the local people, including when or how to burn safely (if burning is necessary), or what help is available (in plowing fire lanes, for example) are more successful.

The principle of face-to-face contact by persons who have legitimacy with the group to be influenced appears to be widely applicable. "One of their own kind," with whom problem groups of youths could more readily identify, has been used in some Forests with moderate success.

FIRE PREVENTION PROGRAMS

Most of our research and application efforts have been directed toward defining and reaching the persons we desired to influence. fluence.

It is also necessary, however, to know something about the organizations conducting a fire prevention program. In our studies of a State agency (Sarapata and Folkman 1970) and of National Forest organizations (Christiansen and others 1976) we have sought to find out how the organization is set up and staffed; the attitudes, values, and expectations of the employees; and how workers at each level define the fire prevention problem, perceive its importance, and evaluate the effectiveness of the methods and techniques used. All of these affect the type of program that can be mounted and the quality of its execution.

Our studies show that although successful fire prevention work frequently requires considerable experience and training, the program personnel had received little specialized training and were expected to pick up the needed expertise on the job.

A study relating personnel characteristics to fire prevention effectiveness[4] found that effective and ineffective employees did not differ significantly in such socio-economic or demographic characteristics as age, race, marital status, rural/urban origin, educational level and employment history. They differed significantly, however, in 1) sense of community, 2) conformity, 3) desire for self-improvement, 4) extroversion, 5) importance given to occupation, 6) acceptance of self and other, 7) ability to communicate, and 8) achievement orientation. Although further testing is needed, these measures appear promising for estimating the potential effectiveness of prospective fire prevention employees.

MASS COMMUNICATION

Agencies responsible for forest fire protection depend upon the mass media--primarily radio and television--for much of their prevention effort. Mass communication is a highly complex process, and there are no simple formulae for its use. The reception of the communication is filtered by the recipient's own values, loyalties, identification, expectations, defenses, and frames of reference; by his total personality; and by the particular setting in which the message is received. The message must be transmitted at a time when the recipient can receive it. Unfortunately, public agencies have limited control over the timing of their releases, dependent as they are on the commercial media for donated public service time.

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[3]Doolittle, Max L., and G.D. Welch
1973. Evaluation of a forest fire prevention program. Report on file, USDA Forest Service, Southern Forest Exp. Stn., New Orleans, La.

[4]Mercer, C.W., and M.H. Kootsher
1974. Personnel characteristics and fire prevention effectiveness. Report on file, USDA Southern Forest Exp. Stn., New Orleans, La.

Most fire prevention effort assumes that most of the forest-using public are basically well-meaning and need only to be informed or reminded of desired behavior in order to comply. Such an assumption is hardly warranted in dealing with vandalistic fire setters. Bernardi (1973) has done some experimental work with TV spots specifically designed to appeal to high-risk youth and young adult audiences, the group in which vandalism seems most likely. Considerable success in changing attitudes and knowledge was achieved when the spots were used in a classroom situation, but results were not measurable when the spots were transmitted over commercial television channels.

DELIBERATE FIRE SETTING

The only research we have done to date on incendiary fires in the West was a study of children known to have been involved in one or more fire incidents (Seigelman and Folkman 1971). Multiple firesetting was found to be a symptom of a number of associated problems (such as excessive activity, aggression, psychosomatic illness, and family and school difficulties) rather than the basic problem. In other words, these were troubled children who happened to use fire as a means of striking back at an unrewarding social world or as a cry for help in coping with overwhelming problems. The characteristics of fire make it a particularly effective means for achieving these desired ends. The child himself may not be able to verbalize the motivation for his actions and it may not be apparent to the unsensitized observer. (I use the masculine gender here deliberately--all the children in the study population were males, and over 90 percent of all children identified with any type of fire incident are males.) Our study makes clear that the terms "wanton," "senseless," and "motiveless" are hardly appropriate for the behavior of these children.

For intervention, early identification of potential problem children is essential. Fire investigation personnel cannot be expected to provide therapeutic assistance, but if their investigation reveals that a child shows several of the symptoms in the pattern, community resources should be called in. They can assist the child in resolving his problems before his behavior becomes irreversibly fixed. Fire problem adults are notoriously resistant to therapy.

The children in our study were chosen because they were already associated with fire setting. But most children who cause fires are apparently normal. Fire has a universal fascination, and most children at one time or another engage in some fire play or experimentation. We were interested in how such children learn the appropriate skills, understandings, and attitudes that mediate against the misuse of fire.

The behavior of normal children in relation to fire was studied in a group of 5- and 6-year-olds attending school at the Harold E. Jones Child Study Center of the University of California, Berkeley. The study focus was their competence in potentially hazardous situations (Bloch and others 1976). This study was an outgrowth of a more extended investigation of cognitive competence and social or interpersonal competence. Base data was accumulated from the time they entered the school at age 3.

Wide individual differences in attitudes about fire were found, despite narrow age limits, relative homogeneity, and the small numbers in the sample available for study. No particular theory of childhood fire-setting behavior was expounded in the research, however, its primary value is in hypotheses suggested for further study, and in implications for modifying the prevention programs of fire protection agencies.

The study findings suggest that fire play in very young children is common and should be viewed as curious, exploratory play rather than the psychologically driven, psychopathological behavior that might be seen in fire-setting by older children.

We found similarities in personality characteristics between children with high accident liability and those showing a keen interest in fire. Both the hazards encountered and the ability to cope with hazards were considered. We concluded that methods used in accident prevention may be adaptable to fire prevention efforts.

It is possible that increased control and risk avoidance would be gained at the expense of spontaneity and creativity. Therefore prevention efforts might better be directed toward improving ability to cope with environmental hazards than toward reducing exposure to risks by discouraging otherwise desirable behavior patterns. The goal would be to help the child develop competence in handling potentially dangerous materials (or situations), as he matures.

Another suggestion drawn from this study is that intervention programs must reach the child early in his life. By the age of five, many children are already interested in and experimenting with fire. Parents have had little help in understanding the process by which children learn to recognize and deal with potentially dangerous situations. Consequently, parental efforts vary in effectiveness. Many parents are particularly lax about teaching their children about fire--over one-fourth of those queried make no attempt to do so. It is apparent that parents who are unsure of how to teach their children safety skills would benefit from being

shown alternatives from which they might select a method suitable to the particular needs of their child and compatible with their own needs and capabilities. There are many difficulties in providing such help effectively, however. One suggestion is a training film for parents illustrating various possible teaching strategies.

Other socialization emphases found in this study to be associated with the development of competence in handling fire materials should be considered. Parental child-rearing practices are needed that encourage the child to assume responsibility, to be independent, and to make rational decisions, in the context of clear parental expectations, respect, and caring. Such practices may be expected to promote the development of ego structures in the child that will both benefit growth and minimize play with fire.

CONCLUSIONS

Fire has had a role in certain ecological systems, and highly trained technicians may use fire as a forest management tool. Today, however, an uncontrolled forest fire is almost always a serious threat to important natural-resource values as well as to human life and property. The majority of forest fires are the result of inadvertent, or negligent--not deliberate--acts of man. They are accidents. Interventive actions that are appropriate for accidental fires are probably not the most effective means of dealing with fires of deliberate, vandalistic origin.

As administrators and as researchers, we tend toward a somewhat parochial, pragmatic view of our problems. We are apt to focus, for example, on how we might deal with expected vandalism at Bass Lake on Memorial Day Weekend, rather than on the causes of such social phenomena.

Although I recognize the organizational restraints under which we operate, I have a sense of futility in attempting to resolve a major social problem through localized intervention. I hope that we can escape, to some degree, from the limited perspectives we have forced upon us, or we force upon ourselves.

"Schlock" is a useful term that characterizes much of our material culture today. It describes gadgets and products that are useless, unworkable, shoddily constructed, and sometimes dangerous. It has also been applied to the products of some social scientists and their camp followers who cater to the public's need for quick, easy answers to a seemingly unending succession of threatening social problems--answers that are palatable but slick and superficial (Claiborne 1971). Often some key word or trend phrase ("future shock," "the naked ape," "the greening of America," "territorial imperative") provides a catchy handle for a simplistic view of uncomfortably complex problems (Martin 1972).

Vandalism, the focus of this symposium, is an imprecise term that covers a variety of types of behavior and motivations. Public repugnance to the highly visible "wanton," "senseless," and "motiveless" destruction of property; public "viewing with alarm," and resultant pressures for action tempt many to accept schlock solutions. My hope is that the members of this symposium will not succumb to the temptation.

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Control of Vandalism in Recreation Areas--Fact, Fiction, or Folklore?

Roger N. Clark[1]

Fact: We know it is true.

Fiction: We know it is not true.

Folklore: We believe it is true, but it may not be.

The purpose of this paper is to provide an overview of the state-of-the-art of knowledge of vandalism in recreation areas and how it can be controlled. Selected literature on this topic is evaluated for practical implications, and procedures for controlling vandalism in recreation areas are described. Research needs are outlined.

This discussion is limited to vandalism in outdoor recreation areas. I have included little material on the more general topic of deviant behavior in recreation areas. Specific types of vandalism and possible variation by geographic areas are not discussed. As an overview, this discussion is not a substitute for a thorough review of the available literature on vandalism and management practices for controlling the problem.

VANDALISM--ITS NATURE AND EXTENT

Other papers in this symposium have described vandalism problems, and I won't present a detailed analysis here. But a few examples may help put my discussion in perspective. Needless to say, vandalism is a common problem in many environments in this country as well as in other countries. Vandalism is a major concern for managers of recreation areas and is recognized as a problem by many recreationists as well (Clark and others 1971b).

The monetary impact of vandalism is staggering. The total yearly loss from vandalism nationwide is estimated at $4 billion (Ward 1973). School vandalism costs over $200 million per year (Anonymous 1973a, 1973b). The U.S. Forest Service reports vandalism in the National Forests cost the U.S. taxpayers over $3 million in 1974.[2] They also report vandalism costs are up 50 percent since 1969. On the Los Padres National Forest alone, costs related to vandalism were more than $170,000 in 1976. Other agencies report equally large losses from vandalism in their recreation areas.

Discussions with several managers in the Forest Service indicate that the costs reported may be underestimated. They feel that reported losses are mainly due to type of damage that are easily observed and for which a dollar value can be determined. Minor impacts (often hard to distinguish from normal wear and tear) are

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[2]Figures compiled in the Recreation Information Management System (RIM), USDA Forest Service RIM Center, Washington, D.C.

generally not recorded even though in total they represent a substantial cost to repair or replace.

The analysis of vandalism impacts from only an economic perspective underestimates the total loss. Perhaps even more serious than the financial loss in many places is the impact on the quality of the recreation environment, which has direct bearing on recreationists' experiences.

Some targets for the vandal cannot be assigned a dollar value. Defacement of natural features, such as trees, shrubs, and rocks, represents a serious loss in environmental quality. Even more troublesome is vandalism of irreplaceable resources such as cultural or historical artifacts, whether they are petroglyphs in southern California or the famous Tlingit totems in southeast Alaska. We all lose when these are destroyed, but the loss cannot be measured in an economic sense.

Recreationists lose in other ways when vandalism occurs. Their recreation experience may be affected by the physical and visual destruction. What is not so obvious is the impact on the recreation management program of the agency concerned (Harrison 1976).[3] For example, although the dollar loss from vandalism may be insignificant compared with the total investment in recreation areas and facilities, vandalism and littering costs on National Forests in 1974 represented over 15 percent of the total Forest Service recreation management and construction budget.[4] The costs resulting from vandalism may directly affect users when scarce budgets for recreation must be used to replace or repair facilities rather than to build new ones or hire additional rangers for public service. For example, the $1.5 million spent on littering and vandalism in California forests in 1974 represents the equivalent of building about 750 new camping or picnic sites.[5] No wonder recreation managers cringe at every initial carved in a bench, written on a restroom wall, or spray painted on a rock bluff.

[3]See also John Zeisel, 1974. Planning facilities to discourage vandalism. American Association of School Administrators, 106th Annual Convention, Feb. 22-24.

[4]Reported in William T. Schlick. 1975. Cy 1974, vandalism and littering on the National Forest System. Unpublished report, USDA Forest Service, Washington, D.C.

[5]Reported in the U.S. Forest Service Daily News Digest, August 15, 1975. This estimate is based on the assumption that new sites cost $2,000 each. For some types of sites the costs may be nearer $4,000 per site.

THE LITERATURE ON VANDALISM

For all the money spent on repairing or replacing vandalized facilities or natural features of the environment, little written information exists about vandalism. Our knowledge of why vandalism occurs or how it can be controlled is very limited. I have reviewed much of what is available, and these comments are focused primarily on the usefulness of the literature from a practical perspective; that is, does it help us understand and therefore control the problem?

The literature on vandalism can be divided into two general categories, that which is supported by data (research) and that which is not. The usefulness of each type is briefly described here.

Literature Not Based on Data

Rhetoric or opinion--Much of what has been written about vandalism is no more than rhetoric or opinion.[6] Such popular articles, books, and even editorials seem to have a large market and are filled with outrage, indignation, and diversity of untested opinions about why vandalism happens and what should be done to control the problem. Any "evaluation" of what works is often subjective, and most of the popular writing focuses on selling the author's pet theories. Rhetorical discussions generally concentrate on spectacular acts and often ignore equally important smaller vandalism problems. Beyond calling our attention to the problem (a worthy objective), such material has little to offer the manager and may even be misleading and dangerous if the many unsubstantiated suggestions are taken seriously.

Theoretical discussions--Another class of literature, although not supported by data, approaches vandalism from a more logical, theoretical perspective. Only a few attempts have been made to verify theories with data (Bates and McJunkins 1962, Bates 1962; Goldman (1961). The writings that fall under this general heading are commonly found in textbooks or academic journals. Usually the author describes or develops a particular theoretical line of reasoning for explaining why vandalism occurs (for

[6]For examples of literature containing primarily rhetoric or opinion, see Anonymous (1967), Bennett (1969), Cardinell (1974), Donahue (1968), Mannheim (1954), Neill (1974), Robarge (1965), Von Kronenberger (1976).

example, aggression, frustration, hostility) and/or how it can be solved (Bower 1954, Clinard and Wade 1958, Cohen 1971, Lippman 1954). Although most papers of this type are devoted to a single perspective, a few have attempted to analyze competing explanations (Jeffery 1971, Ward 1973). Most of the solutions for controlling vandalism proposed in theoretical discussions are logical extensions of the author's particular theoretical perspective. As such, they are only as good as the theory, and most must be judged as unreliable on those grounds alone; that is, they have not been tested. Some suggested solutions are described later.

Research-based Literature

Discussions falling into this category imply that reliable data support the conclusions drawn by the author. Objectivity is a key concept, although theoretical perspectives usually play an essential role in designing the research and/or interpreting the findings from a study. There are two general types of research-based articles, descriptive and evaluative.

Descriptive research--Descriptive studies are the most common type of research on vandalism. Questions about the nature of the vandalism problem, who is involved, when and where vandalism occurs, and how much exists have been addressed in several studies[7] (Campbell and others 1968, Clark and others 1971a, 1971b; Cardenuto and McCrea [n.d.]; Cardinell 1969; David 1971; Fandt 1961; Mannheim 1954; Martin 1959; Matthews 1970; Perk and Aldrich 1972). This type of information is a starting point and essential to establishing a baseline for time-series studies if the work is well done. Unfortunately, most of this type of research has been based on reported rather than observed behavior, and what is reported is often unreliable. Only a few studies report direct observation of the problem (for example, Clark and others 1971a). Most ignore the many smaller acts of vandalism. Descriptive research is an essential first stage in understanding and thereby controlling vandalism; but in the absence of further evaluative research, it really doesn't directly help control the problem.

Evaluative research--This type of research involves explicit evaluation of the effectiveness of specific programs or strategies for controlling vandalism. The experimental demonstration of cause and effect allows the manager and researcher to establish what really works and what doesn't. As such, this research provides the single most important type of information from the manager's perspective because he is trying to control the problem. But this type of study is virtually nonexistent for vandalism. Only one source could be found where an objective evaluation had been conducted; in this case, the author demonstrated the effectiveness of a community education program (Palmer 1975). Often the "evaluation" of what works and what does not is based on subjective criteria; that is, it "reportedly" worked somewhere (Irwin 1975, Knudsen 1967b, Martin 1959, Wilson 1964). Consequently, what really works and what doesn't--when, where, and why--is impossible to say. We just don't know. More evaluative studies by managers as well as researchers are necessary to provide important answers that can help reduce vandalism in a variety of settings.

Guidelines for Using the Literature

The watchword in using the literature on vandalism is "caution." If the content of articles or books could be easily classified into the categories I've described, then evaluating their worth from a practical perspective might be relatively easy. But many papers contain elements of all types, making it difficult to separate fact from fiction from folklore.

The buyer must truly be cautious when it comes to finding a solution for vandalism in the literature. Even when a solution seems to work in one case, it won't necessarily work everywhere. Variation from situation to situation requires some evaluation to test the effectiveness of proposed control procedures.

A useful approach for using literature is to identify all the unsubstantiated claims made by the author. Much of what is written is not supported by fact, and a great deal is not even supported by rational arguments.

Even papers with "data" must be viewed with caution. The work may be misleading if the problem under study is couched in different terms from yours, or it may be based on poorly conceived research. Interpret the data yourself to see if you agree with the author. Would you invest your money in a program to stop vandalism based on what you've read and the solutions proposed? If not, keep looking!

ISSUES RELATED TO VANDALISM

Two issues commonly discussed in the literature have important practical implications for understanding vandalism and thereby reducing its impacts: What vandalism is and what causes it.

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[7]Paul Petty
1966. Vandalism. Taken from his thesis, "Vandalism in Natural Forests and Parks." Colorado State University.

Definitions of vandalism--a great deal of confusion exists concerning what vandalism really is (Clark and others 1971b, Cohen 1968, Eliot 1954, Harrison 1976, Smith 1966, Ward 1973, and Wilson 1964).[8] Although there is little difference of opinion about the major acts of destruction, considerable differences do seem to exist concerning some actions in recreation settings.

What is "proper" behavior is not clearly defined; many times an act of vandalism as defined by a manager may be very appropriate from a user perspective. In some cases, recreationists who have little contact with the environment may really not know what is defined as vandalism by managers. In other cases they may know but disagree. Examples include throwing axes into trees, carving on tables and benches, chopping down trees in campgrounds for firewood or for more space. Even though rules exist which prohibit such activities, the fact that users don't understand or agree with them may result in vandalism by definition only. Considerable research has documented this difference in perspective between recreation managers and users (Clark and others 1971b; Hendee and Campbell 1969). Understanding the basis for this difference is essential for any approach to controlling the problem. For this discussion, vandalism is the result of any act (intentional or unintentional) which damages either natural or manmade features of the environment.

Motives for and causes of vandalism--Understanding the motives for and causes of vandalism is an important part of controlling the problem, and many authors have dealt with these topics (Clark and others 1971b, Harrison 1976, Hendee and Campbell 1969, Eliot 1954, Jeffery 1971, Murphy 1954, Perk and Aldrich 1972, Scott 1954, Schaffer 1975, and Ward 1973).[9] But there is no proven theory of the causes of vandalism. Many theories or perspectives attempt to explain the problem from biological, psychological, or sociological perspectives. No one that I know of has tried to integrate these approaches, and most authors ignore the extremely important effects that the environment and specific situations play in explaining vandalism (Jeffery 1971). One perspective inherent in many of the discussions of motives or causes warrants comment here. Although many people fail to recognize any rationale behind vandalistic acts (they are often thought of as strictly a wanton, malicious activity), several writers have argued that this is not so (Campbell and others 1968, Clark and others 1971b, Cohen 1968b, Eliot 1954, and Ward 1973).[10] Usually a reason can be found for vandalism; for example, play, lack of alternatives, vindictiveness (Cohen 1968c, Madison 1970, Ward 1973). And, although vandalism with a reason behind it is still inappropriate, understanding the underlying motives and causes is important in its eventual control.

SOLUTIONS[11] FOR CONTROLLING VANDALISM

Education

A common approach proposed for control of vandalism is to educate the public (recreation users in this case) about vandalism; that is, make them aware of why it is bad and the need for their help in solving the problem. Traditional educational programs have focused on instilling proper values and attitudes regarding vandalism. The basic assumption is that proper behavior will then result; people won't vandalize or let vandalism occur. Much evidence, however, suggests that attitudes about an issue or problem may be different from one's behavior. For example, attitudes regarding littering have been shown to be very different from actual littering behavior--we may believe it's bad but litter anyway (Clark and others 1972, Heberlein 1971).

In review of the sociology literature on research concerning attitudes and behavior, Wickler (1969) concluded that only about 10 percent of the variation in actual behavior could be explained by knowledge of attitudes! The basic reason for the discrepancy is that many factors are related to actual behavior in addition to attitudes, especially features that vary from one situation to another and make different behaviors attractive or available. The social group one is with, for example, can either increase or decrease the likelihood of acts leading to vandalism. Therefore, in terms of the problem facing managers of recreation areas, this educational approach has limited potential for solving the vandalism problem since we're primarily concerned about behavior. If Wicker's conclusions are valid as applied to vandalism, traditional education (focusing on attitudes and values) would result in no more than a 10 percent reduction in vandalistic behavior, even if the targets

[8]See footnote 3.

[9]See footnote 3.

[10]See footnote 3

[11]Solutions to vandalism are discussed by Anonymous (1967, 1973a, 1973b, 1973c), Bennett (1969), Cardenuto and McCrea (n.d.), Irwin (1975), Kelly (1973), Knudsen (1967a, 1967b), Martin (1959), Matthews (1970), Neill (1975) Petty (1966), Ward (1973), Weinmayer (1973), and Wilson (1964). (Also see footnote 3).

for the educational programs are potential vandals and the intended attitudes and values are generated by the program. Cohen (1968a) even thinks that publicity about a problem may backfire; it may even elicit problem behaviors. For example, publicizing a campaign to remove graffiti from rock walls in a recreation area identifies a target for future vandalism: "Wouldn't it be fun to spray paint the same wall the day after the cleaning crew leaves!"

Regardless of the approach used in educational programs, some general rules of thumb may make them more effective:

1. An effective educational program will require that the manager understand user motives and desires. Considerable evidence suggests that managers and users often disagree on what is appropriate, including things which are labeled as vandalism by managers (Clark and others 1971b, Hendee and Campbell (1969). Managers are often misled when they interpret user motives and desires by their own value systems. Identifying areas of disagreement (and reasons for them) is an important starting point for understanding the problem and developing effective educational programs.

2. Users must also understand the manager's motives. Managers often forget that they may be part of the problem. Both individual and organizational attitudes (and behaviors) are important and may have an impact on users' perceptions and behavior. Attitudes about recreation in general (is it legitimate or not?) and toward specific users (motorcyclists, hikers, etc.) affect our behavior in ways that may either reduce or increase problems. Do you favor "hard or soft sell approaches"; that is, educate or arrest? Do you ignore minor acts of vandalism (or other problems)? If so, you may be condoning the problem in the user's mind.

Division of responsibilities on a functional basis within an agency can result in a disastrous situation if, for example, patrolmen responsible only for fire prevention ignore other recreation-related problems in their areas. The public may be misled by agency behavior if inappropriate acts are ignored in one case but acted upon in another. Different management policies between agencies further confuse and frustrate users.

Many well-intentioned attempts by managers to help solve important problems may result in vandalism. This often happens when management actions conflict with user goals. For example, roads are often closed for lack of maintenance budgets, concern over erosion, fire hazard, etc. Gates or signs which are an attempt to implement the manager's decisions are torn down, shot up or driven around, often damaging natural environmental features. Why? Perhaps in some cases this vandalism occurs not for its own sake but to allow the "vandal" to achieve some other goal--getting to a favorite lake or campsite, for example. Public campgrounds are often closed entirely or in part during the "off-season" to save scarce recreation management dollars, a worthy objective. But vandalism (or at a minimum, extreme frustration) can occur for some users when they feel confined and crowded without apparent reason in certain areas not to their liking or when a favorite, more isolated site may be just beyond a gate or sign over a barrier post or pile of dirt. Who is guilty? Certainly we cannot excuse the vandalism, but understanding why it happens may help us identify conditions where management actions can lead to vandalism.

We need to continue to ask why we are doing what we do and will it make sense and be agreeable to users. Conflicting goals and values must be identified and effective two-way communication and education initiated to minimize the impacts from such disagreement.

3. Attempts to control vandalism or other problems with messages lacking rationale are often doomed to fail. If people don't understand the "why" behind the do's and dont's conveyed in signs, vandalism can result.

Why can't cars be driven off parking pads?
Why can't tables be moved (even when chained down)?
Why can't more than one family camp at each campsite?
Why can't a tree be chopped down for firewood or to get a pickup camper into a site?
Why can't initials be carved on benches or tables or trees?

Signs (or other communication mediums) should convey the reason for the regulation whenever possible. Such "positive signing" would, I think, help eliminate some vandalism in many areas. Certainly, effective enforcement procedures will still be necessary for people who ignore the most rational rules.

Direct Management

A variety of ways exist for directly managing areas, facilities, or natural environmental features to reduce or prevent vandalism. Some of these approaches have been covered in other symposium papers, and I will only briefly review them here.

Design of sites or facilities--Considerable effort has been expended to design vandal-proof sites. Much has been written about this

topic (Anonymous 1973c, Miller 1973, Spalding 1971, Weinmayer 1973). Although there have been many successes (Weinmayer believes proper design can reduce vandalism by 90 percent), my impression is that we often fail in this approach. Many times it seems that when a particular type of vandalistic act is prevented through design, another unanticipated problem results. For example, in a campground I recently visited, restroom walls in the area were made of material harder than knife blades to prevent vandalism. Indeed, carving and scratching with knives was eliminated. But the problem was not solved because the native rock in the area was harder than the construction material, and carving and scratching with rock resulted. Although design may be an important element in preventing some vandalism, little evidence exists for a foolproof solution through design. New ideas emerge daily, but many have not been evaluated for their effectiveness in different locations.

Maintenance--Replacing or repairing the evidence of vandalism as quickly as it occurs is proposed as another strategy for solving the problem. The assumption is that by keeping the area nice it will stay that way. A great deal of folklore exists about the effectiveness of this procedure, but little has been verified. To the extent that the problem continues (which it often does) maintenance is not a complete solution. We often have to "re-repair" (Cardenuto and McCrea n.d.). Perhaps vandalism may be reduced to some extent by maintenance, but the evidence available does not allow a clearcut answer for every case.

Fees--Some managers believe vandalism and other problems such as littering are reduced when fees are charged. The belief is that users tend to have more at stake and greater feelings of ownership in an area where they pay to stay. An alternative view is that when fees are charged, users may feel they have more right to "tear it up." There is no reliable information to support or refute either viewpoint. U.S. Forest Service figures indicate that costs for vandalism and littering in the National Forests were greater per user in areas where fees were charged.[12] However, reasons other than the fee itself may explain this difference: Some Forest Service managers feel that these data underestimate the true cost from vandalism, perhaps more in one type of area than another; more people generally use fee areas; fee areas generally have more facilities to be vandalized; and the introduction of fees may affect the type of clientele an area receives. Other unidentified factors may also be involved.

[12]See footnote 2.

Removal of opportunity--Eliminating the opportunity for vandalism by removing facilities, closing areas, or hiding what can be vandalized has been proposed as a solution and is done in some places. We can take away or not provide wooden posts, tables, restrooms, signs, etc. We can close access to large areas such as commercial or public forests, and we can close entry to specific areas by barricading roads (subject to problems discussed earlier). Or we can hide valuable objects such as cultural or historical artifacts. In general, this approach will work. Indeed, it's about the most predictable solution available. However, in doing so, we must consider the negative impacts on other users who are not responsible for the problem. If this prescription were followed in areas with major vandalism problems, in most cases, the majority of well-intentioned users would suffer because of a relatively few people. In the case of irreplaceable objects such as historical artifacts, perhaps we have no solution but to remove or hide them until such time as they can be protected. For other things which can be replaced, the relative advantage gained from this remedy is not so easily ascertained.

Detection and Enforcement

Increased detection and strict enforcement of laws, policies, and rules are often proposed as a way to deter vandalism (Anonymous 1973a, Thomas 1964). To be most effective as a deterrent, this approach must result in punishment; the potential vandal must realize he will probably be seen, caught, and punished (Jeffery 1971). Unfortunately, this is often not the case for most crimes against the environment in this country (Jeffery 1971) and certainly not in most recreation areas (Clark and others 1971a, 1971b). This is not to say, however, that enforcement programs are worthless, only that they are a small part of the solution. Possible ways to increase the effectiveness of detection and enforcement programs in recreation areas include increasing the number of patrols, adjusting patrolmen's hours (or those of cooperating law enforcement agencies) to match recreation use and problem times, hiring watchmen (Matthews 1970), and establishing entrance stations where each party is contacted and, perhaps, registered in particularly bad areas.

Public Involvement

Involving the recreating public in helping to solve vandalism is a new approach which has been recently proposed and used in some areas. A few authors have dealt with this approach (Anonymous 1967, 1973b; Clark and others 1971a, 1971b; Neill 1975; Ward 1973; Wilson 1964). The focus is to find ways to change users' behavior to reduce their own vandalistic acts as well as those of other people.

Research on depreciative behavior, including vandalism in outdoor recreation settings, indicates that this approach has tremendous potential for reducing the problem. In one study nearly 80 percent of all depreciative acts occurred in the presence of other people, yet no one got involved (Clark and others, 1971a, 1971b; Campbell and others, 1968). Why? Possible explanations for the noninvolvement include apathy, fear or threat from getting involved, lack of agreement on the definition of what is proper, and lack of knowledge about how one can get involved. The point here is that we can't assume people won't help. There may be things we can do to encourage their involvement without threat to them.

A variety of ways can involve people, depending on the objective. Some basic assumptions and approaches are briefly described here.

Involve the victim--On public recreation lands, the victim of vandalism and other types of depreciative behavior is the public. Since the research described above indicates that often people are present when these acts occur, what can they do to help? How can managers increase user involvement? Alternatives range from encouraging users to handle problems themselves (and showing them how) to contacting proper authorities and giving them essential information. Others advocate paying people for information about vandals they observe. Perhaps some sort of "help the ranger" campaign might encourage people to help reduce vandalism. Part of the solution certainly will be to develop procedures whereby the public can get involved with little personal threat.

Involve the culprit--The objective here is to provide a constructive alternative to destructive behavior. This approach has been used for both adults and children in a variety of areas. It seems to work because it gives people involved a stake in the problem. For example, in response to vandalism of recreation cabins during the winter season by snowmobilers, the suspected culprits were organized and asked to help protect the homes; they did and vandalism ceased. Two boys in a developed campground who were suspected of vandalizing restrooms and nature trail signs were involved in a litter pickup program to help the campground ranger; vandalism ceased[12] (Clark and others, 1972). And in a forested area in Spain, youths suspected of vandalizing birdcages for protecting certain species were involved in constructing new cages; vandalism ceased.[13] Other similar management approaches seem possible.

Involve people in formal programs--The two approaches described above focus on involving people informally. In some cases, programs for specific individuals assuming some formal responsibilities may be useful. Individuals or couples may be selected and trained to perform some of the duties of agency personnel. Their presence in problem areas can increase the manager's visibility and allow one-to-one contacts with users.

In the West, a "campground host" program has been implemented in several areas. The volunteer hosts, usually retired married couples, live on campgrounds, and their presence is reported to have decreased vandalism problems. The public has enthusiastically supported this effort, and many people have volunteered their services. Other problems have also been reduced. For example, in one U.S. Forest Service location where the host program was in effect, local managers indicated that as vandalism and other depreciative behaviors decreased, voluntary compliance in turning in overnight camping fees increased. Other formally established programs such as the "Older American" program have been used in other locations for similar purposes.

Although campground hosts usually have no formal enforcement authority, they have been successfully used when problems in selecting appropriate people are overcome. In Australia, formal authority has been given to a ranger force made up of citizens, and some successes are reported.[14]

A public involvement program should be focused at a variety of levels. It can include year-round involvement through organized groups as well as routine, ongoing efforts during the main recreation season such as the campground host program. The public that moves through the area and stays for short periods only should be involved. So should both culprits and victims. Identifying and evaluating ways to accomplish public involvement at all of these levels are important concerns for both managers and researchers.

[12]Roger N. Clark. How to control litter in recreation areas: The incentive system. In preparation for publication, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

[13]Personal communication with Antonio Nadal Amat, Head of the Department of Environmental Analysis, Madrid, Spain.

[14]Personal communication with Allan Viney, member for Wakehurst, Legislative Assembly of New South Wales. Sydney, N.S.W.

Treat Vandalism as a Cost of Doing Business

A final approach to vandalism is to treat it like shoplifting: We do all we can to stop it, including proper design, maintenance, and replacement; but we assume some will occur and charge the consumers (users) the resulting cost. In this view, vandalism is accepted as a fact, one of the impacts from recreation use.

Available statistics indicate a relatively small cost per visitor for vandalism in outdoor recreation areas. On the National Forests, the average cost for vandalism and littering was approximately $0.03 to $0.10 per visitor day during 1974.[16]

Although many legal and political problems exist, establishing a user surcharge for vandalism would insure that other options are not foregone if the scarce recreation management budgets are used in repairing or replacing damaged facilities. Such a surcharge would make users clearly aware of the financial impact of vandalism.

SUMMARY OF POSSIBLE SOLUTIONS FOR CONTROLLING VANDALISM

A variety of procedures for controlling vandalism have been proposed and readers are encouraged to make their own judgment about the relative advantages and disadvantages of each. My conclusion is that none of the alternatives I've described offers a complete solution to vandalism, problems are still increasing, and the level of uncertainty for complete success in using any of the approaches is high. We don't know at this time what works best, when, where, how, or why. A great deal of folklore exists about the "best approach," and many of the alternatives may be costly and risky. But any long-range solution will require a variety of approaches.

Prevention programs should focus on the various social, political, and physical-environmental factors to reduce vandalistic behavior and increase antivandalistic behavior. We know little about how all the possible controlling factors interact, and research is necessary to identify the important factors and evaluate their relative advantages and disadvantages in a variety of conditions.

Some vandalism problems may be controllable, others may not. In the absence of severe restrictions on use and users, we may have to accept some forms of vandalism because the controls may be worse than the problems they are meant to solve.

[16]See footnote 2.

RESEARCH ROLE AND NEEDS

Several authors have recognized the need for more research on vandalism (MacNeil 1954, Palmer 1975), particularly the need for evaluation (David 1971). To be maximally useful, research on vandalism and other forms of depreciative behavior would be based on close communication and cooperation with managers. Researchers and managers both learn in ongoing consultation. Researchers must maintain contact with on-the-ground managers in a variety of areas to insure an appreciation of real-world problems.

An effective research effort to provide useful information for understanding and controlling vandalism should be based on a broad level involving several regions of the country and various agencies and private land managers. This will allow for analysis of both common and unique problems. But we also need to focus on specific situations to control specific problems. Although different kinds of vandalistic acts and recreation areas are similar, much variation exists that may affect the usefulness of "proven" solutions in one area when applied in another.

An important need is establishment and implementation of procedures for objectively identifying and measuring the impacts (physical, as well as those on the users' experience) from vandalism <u>and</u> other depreciative behaviors. Good descriptive baseline data are essential for evaluating the effectiveness of procedures to control the problem.

Another need is development of an understanding of the dynamics of specific locations (and sites) and the needs and behaviors of specific user groups as related to vandalism and other problems. We must design, test, and evaluate programs to fit the needs of specific areas and users of those areas.

CONCLUSION: A CHANGE IN ORIENTATION IS NEEDED

In the absence of any definitive solutions, what can planners and managers do to minimize the vandalism problem? Although no one has the entire answer to this question, I want to offer my perspective on several important points.

The vandalism problem should not be considered separately from other depreciative behaviors such as nuisance behavior, rule violation, and littering. The causes for and solutions to these other problems may hold important clues for reducing vandalism. The campground host program, for example, demonstrates the impact one procedure may have on a variety of problems including vandalism. Past research

on litter control indicates that by involving the public in control of litter, vandalism and other problems may decline.

We need to develop a program that integrates a variety of approaches (Jeffery 1971, Harrison 1976, Weiss 1974). There is no single best answer now and there probably never will be a blanket solution without considering others (Wilson 1964). All the procedures described in this and other papers in this symposium should be objectively evaluated for their usefulness.

And a variety of perspectives must be considered to understand and control vandalism. This includes the social scientist's (psychologist, sociologist, etc.), the designer's the manager's, the planner's, and, most important, the user's perspectives.

Above all, it is important when faced with a problem as tough as vandalism to keep a positive attitude. There are no magic answers (Harrison 1976). The problem isn't going to go away, and the danger is that the manager will become so frustrated with day-to-day problems that he will deal ineffectively with recreationists who may not recognize the magnitude of the problem. Recreation is legitimate and worthwhile, but it has impacts and costs like all other resource uses.

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NATIONAL FOREST SYSTEM
COOPERATIVE FORESTRY
FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE
FORESTRY RESEARCH

FORESTS AND WATER:
effects of forest management on floods, sedimentation, and water supply

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1976. *Forests and water: effects of forest management on floods, sedimentation, and water supply.* USDA Forest Serv. Gen. Tech. Rep. PSW-18, 115 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

From the background of more than 100 years' collective experience in watershed research and from comprehensive review of the literature of forest hydrology, the authors summarize what is known about the forest's influence on the water resource, particularly the effects of current forestry practices. They first examine the fundamental hydrologic processes in the forest. They then discuss how water supply, floods, erosion, and water quality are affected by timber harvesting, regeneration, tree planting, type conversion, fire, grazing, and the application of fertilizers and pesticides. They consider and present the special problems of fire-prone chaparral, phreatophytes, wetland forests, and surface-mined sites. Finally, they assess potential increases in water yield that might be achieved by forest management in each of six major forest regions in the United States and venture some predictions about future management of watersheds. Nearly 600 references provide a fairly comprehensive overview of the literature.

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Retrieval Terms: forest influences, water yield, flood control, erosion, sedimentation, water quality, multiple-use, watershed management, forest fire, logging, forest grazing, wetlands, phreatophytes, surface mining.

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Relationships between forest and water—both imagined and real — have played an important part in the conservation movement. In Europe these relations were recognized as early as the 13th century. In the United States they were embodied in 19th century legislation to conserve the forest. In 1876, concern for water motivated the first attempt by Congress to create national forests from public domain in the West: "for the preservation of the forests of the national domain adjacent to the sources of the navigable waters and other streams of the United States," and to determine what should be reserved in order to prevent such rivers from becoming "scant of water." Legislation early in 1897 for reservation of forested public lands was followed the same year by an act that specified their water-control as well as timber-supply functions: "no public reservation shall be established except to improve and protect the forest within the reservation or for the purpose of securing favorable conditions of water flows and to furnish a continuous supply of timber."

The ascribed roles of the forest in relation to water were employed even more strongly to justify the purchase of 23 million acres of forest lands in the East for national forests. Out of this effort, but not without considerable controversy, came the 1911 Weeks Law that provided "for the protection of the watersheds of navigable streams and to appoint a commission for acquisition of lands for the purpose of conserving the navigability of navigable rivers." At question, both before and after passage, was the thesis that streamflow is regulated by the forest. Conservationists taking the affirmative side had little more to offer for justification than observation and intuition; engineers, in opposition, had no better argument than some exceptions to observations and a strong disapproval of the intuitive approach. No firm data were available to support either side.

Obviously, the subject required research, and in 1909 the first forest watershed study in the United States was started at Wagon Wheel Gap, Colorado. Increasing flood damage throughout the next two decades kept the forest and flood issue alive. In the early 1930's, the U.S. Forest Service started additional research at the San Dimas Experimental Forest in southern California, the Sierra Ancha Experimental Forest in central Arizona, and the Coweeta Hydrologic Laboratory in western North Carolina.

Before many results were forthcoming, however, the Omnibus Flood Control Act passed in 1936 gave the Forest Service responsibility "for conducting flood control surveys on forested watersheds to determine the measures required for runoff and water-flow retardation." Of necessity research programs were expanded, and in the 1940's their results began to set forth the forest's influence on water yield, floods, and erosion. Out of this research came two salient conclusions: (1) forest cutting and forest growth can have a major influence on water yield; and (2) the forest, because of its full occupancy of site, provides the maximum opportunity for controlling runoff from flood-producing rainfalls; even so, the forest cannot prevent all floods.

By the 1950's watershed management research divisions had been established at all nine Forest Service Experiment Stations. By the 1960's the number of forested experimental watersheds under study reached 150. By 1970 almost 2,000 papers had been published describing results of research on watershed management. In addition, courses in forest influences, forest hydrology, or forest watershed management were being offered at 25 of the 32 accredited forestry schools (Sopper 1970), two textbooks had been published, and two international symposia in forest hydrology had been held.

Out of this growing body of knowledge about the forest's influence on streamflow came a new subject matter in forestry; namely, forest watershed management. Legal recognition came in the Multiple-Use Sustained-Yield Act of 1960, which authorized the establishment and administration of national forests "for outdoor recreation, range, timber, watershed, and wildlife and fish purposes."

In the 1970's there is growing awareness of the forest's influence on water yield, floods, and water quality. Water shortages are becoming prevalent and threaten to become more so, when flood damages have reached new peaks, and when pollution of water supplies is causing increased concern.

Knowledge about relationships between forestry and water has been greatly enhanced during the last three decades. This report summarizes and evaluates research evidence and other information pertinent to the forest's influence on water,

especially on how this influence can be managed for man's benefit so as to increase water yield, reduce floods, and improve water quality.[1] Though we hope our summary will be useful to fellow forest hydrologists, our principal aim is to provide students, practicing foresters, and other professionals an insight into current knowledge of relations between forestry and water. These persons need help in water supply management because of present and predictable increased pressures on forest land and the emphasis today on multiple use of these lands. We make no claim that the findings reported here or our interpretations of them is a basis for any management decision. Management is site specific and the research results were site specific. But since sites are generally different, integrating sites and management is a task for professionals.

After that brief introduction, this report (1) discusses the hydrologic processes that govern the movement of water in the forest, (2) considers forest treatment and water, the effects of management practices and other agents on the water resource; and (3) discusses some local and regional extreme situations. Next, the paper discusses generally the potentials for management — first with respect to water yield, floods, and water quality; then it presents the possibilities for improving hydrologic management in three regions in the East and three regions in the West. Finally, the report assesses the place of forestry and water in tomorrow's society.

In reporting quantitative results we have retained common U.S. rather than metric units to avoid problems of duplicate numbers and problems of significant figures, and because we still "think" in nonmetric units.

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[1] Forestry is the science, art, and practice of managing forest lands and their natural resources. Since the dividing line between forest and nonforest is often hazy, precise definition is not easy. The term "forests," as used herein, includes all tree and shrub lands where canopy cover is greater than about 15 percent of the land surface.

I - HYDROLOGIC PROCESSES

Forestry and water are inseparable. Forests and water occur together and they interact. Plant a tree and it will use water; cut a tree and its water use ceases. Trees mark where water is: the greater water-providing regions of the United States are largely tree-covered. These forests require a minimum of about 20 inches of water per year but use much more than that if it is available. Water in excess of this use penetrates the permeable forest soil to underground storage and streamflow except for a small amount that evaporates from the forest floor or snowpack. Water released from the forest is generally a beneficial component of the water supply needed by man, but occasionally an excess of water from forest lands contributes to damaging floods.

The wide range among forest types in the United States, in the amount of precipitation they receive and in the quantity of streamflow they yield *(fig. 1)*, complicates the evaluation of the hydrologic processes in forests. (The maps here show only the conterminous United States; if Alaska and Hawaii were included, the range would be even greater.)

The circulation of water from the seas to the atmosphere, to the ground, and back to the seas, is called the "hydrologic cycle." This cycle can be considered a system of water-storage compartments (the atmosphere, the soil mantle, the stream, etc.) and the flows of water (either solid, liquid, or gas) within and between them *(fig. 2)*. We call these individual storages and flows "hydrologic processes." Division of the cycle and the naming of its components make it easier to study how water and energy enter the system, and how they are stored, lost, and delivered. We hope, too.

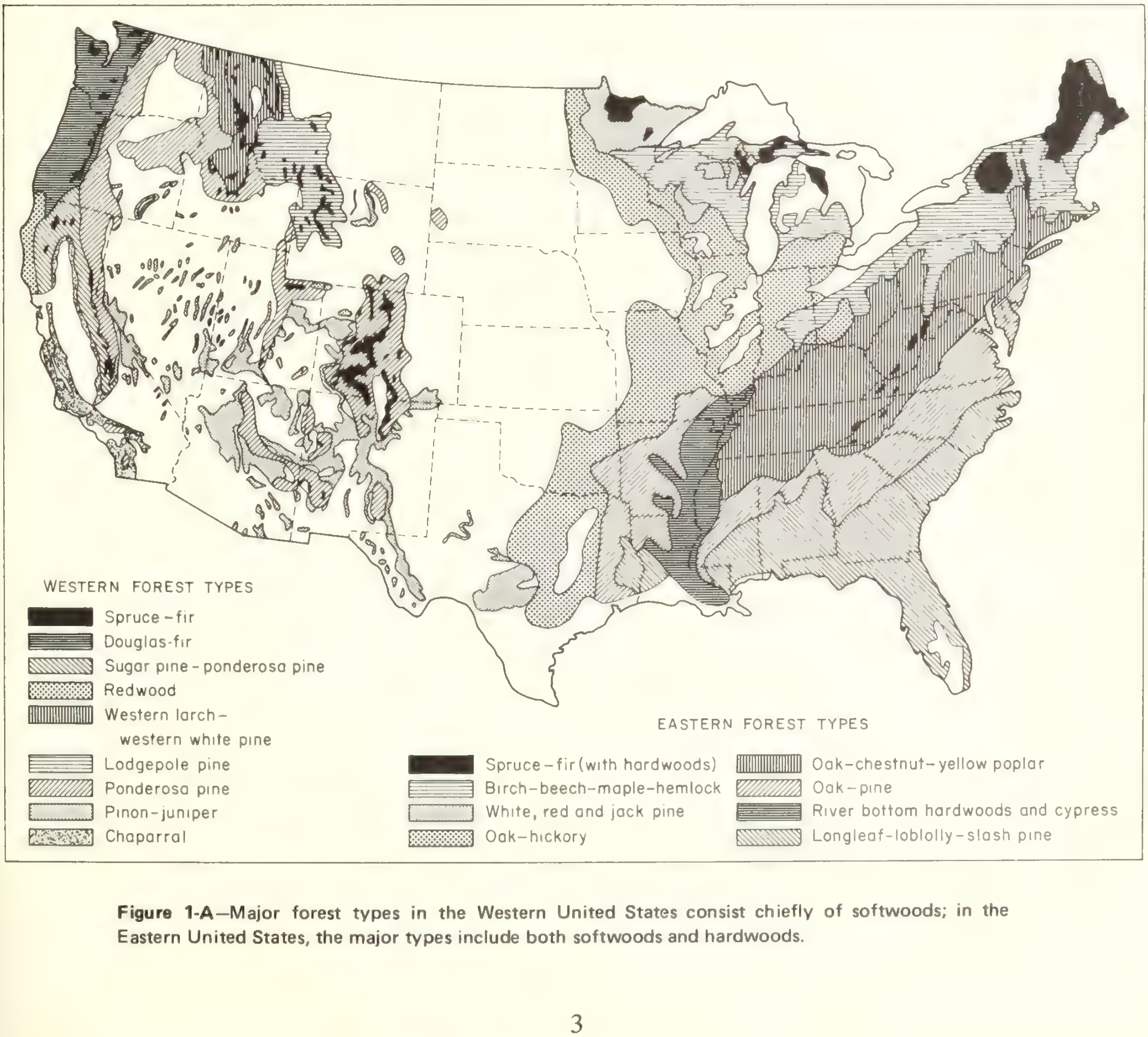

Figure 1-A—Major forest types in the Western United States consist chiefly of softwoods; in the Eastern United States, the major types include both softwoods and hardwoods.

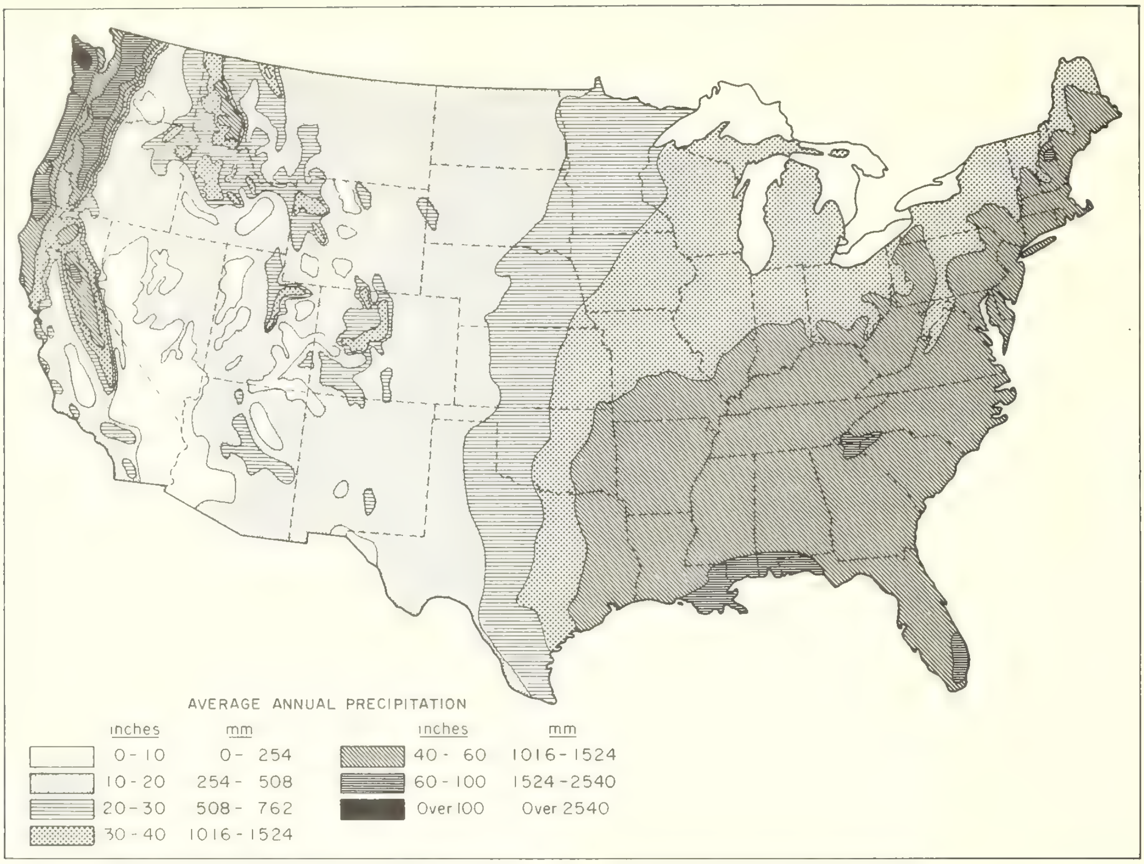

Figure 1-B—Average annual precipitation in the conterminous United States ranges from less than 10 inches to more than 100 inches.

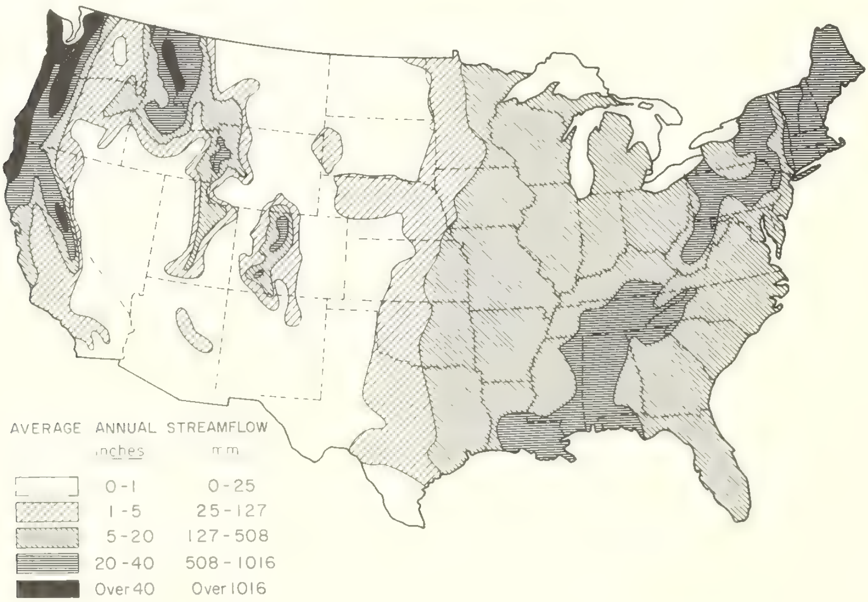

Figure 1-C—Average annual streamflow in the conterminous United States range from less than 1 inch to more than 40 inches.

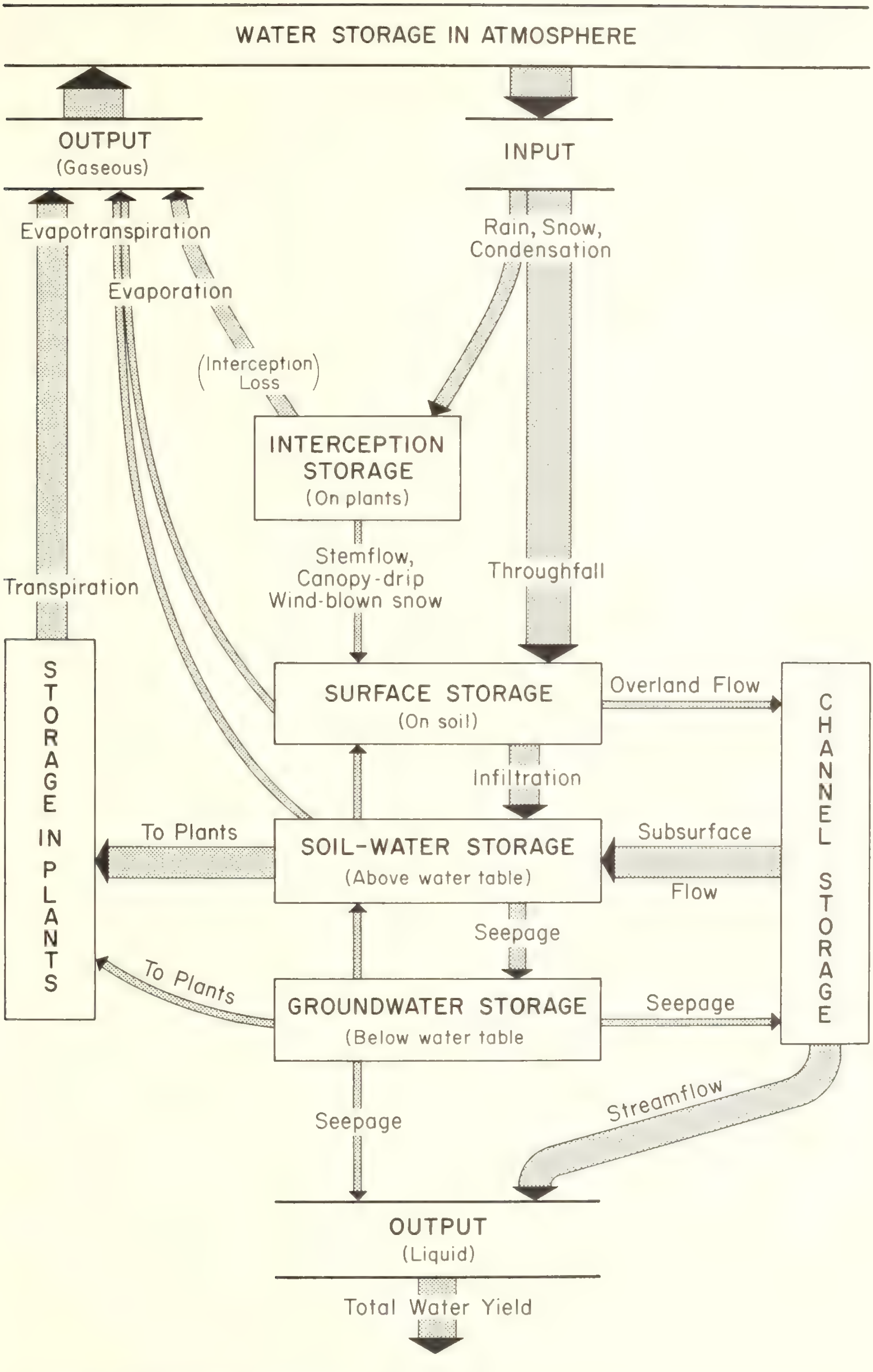

Figure 2—The hydrologic cycle consists of a system of water-storage compartments and the solid, liquid, or gaseous flows of water within and between the storage points.

that the processes are additive so we can predict water supply, floods, and water quality by summing the data on the individual processes.

Measurements of individual processes are subject to considerable error, biases, and faulty criteria of evaluation. In reporting their results, researchers usually have not worried much about rejecting a hypothesis when it was proved to be true (Type II Error); they say, "The differences were not significant." The results reported here, then, require further scrutiny by the user; this report is essentially an introduction.

Hydrologic processes are usually studied in what appears to be their logical time sequence, such as the inputs from precipitation, interception by vegetation, surface storage and flow, subsurface storage and flow, groundwater flow, and streamflow. Of course, each of these processes may be subdivided; for example, precipitation, the first phase of the hydrologic cycle, may be subdivided into rain and snow. Our understanding of hydrologic processes has improved by study of the energy relations that affect them; for example, the energetics of rainfall impact on the soil, the effects of solar radiation on snowmelt, and the sources of energy required to evaporate water. Each hydrologic process in the forest ecosystem is influenced by the type, size, age, and arrangement of trees. Forest units are highly diverse, and this complicates their management for water as well as for other goods and services. How precisely has the forest hydrologist determined the relations between water and the forest? Let us examine the evidence.

Hydrology in the Forest

The conditions under which the forest functions hydrologically differ greatly in time and space. Forest types and stand conditions, forest soils, and even forest topography have developed from diverse parent geologic material through a long succession of tectonic events, variable climate, and sequences of other violent natural events. One 40-acre tract may perform like another 40 acres, but probably not like the 40 immediately above or below it on the slope, or like the one on the facing slope. And each tract may perform differently from all others.

The hydrologist seeks quantitative measurements of each process, the conditions that influence each, and of the interactions between processes. He uses relationships derived from these data to predict the performance of the processes in other areas where he can determine the conditions that control them. The result is a series of estimates ranging from distribution of rainfall and snowfall, through the role of energy in the water balance, to the flow of water within and out of the forest areas under consideration.

This report updates the knowledge of processes that was so well documented by Kittredge (1948) in *Forest Influences,* Geiger (1965) in *The Climate Near the Ground,* and Molchanov (1963) in *The Hydrological Role of Forests.* What have we learned in the years since these texts were published? Forest hydrology has operated as before; however, our improved understanding and quantification of its processes have provided a better basis for deciding how to manage forests for water supply and control.

Three broad groups of interacting hydrologic processes are those that affect (a) rainfall, snowfall, fog drip, and condensation; (b) water storage and delivery; and (c) energy transfer, especially in evaporation. For each process, we present some measurement results and their variability and discuss how these affect the management of forests for water supply and control. We will describe how the hydrologic processes affect each other, and the limitations of our ability to measure the processes and integrate them into models of watershed performance.

Water Inputs

Precipitation Measurement

Water introduced into the hydrologic cycle may be as rain, atmospheric moisture, or snow. Measurements of this moisture are subject to sizable and unknown error — particularly for snowfall, misty rain, or fog. Even rainfall may be subject to large errors in measurement. Court (1960) wrote: "Two identical rain gages 10 feet apart on a windy ridgetop can differ consistently in catch by 50 percent of the smaller." Glander (1966) reported average errors of 18 percent and maximum errors of 40 percent in measurements of precipitation.

Variation of precipitation in time and space can mislead one in estimating the average precipitation for watersheds. These variations are associated with different synoptic events in complex ways. Hiser (cited by Singh 1968) lists six types of events that produce precipitation in Illinois: cold front, warm front, stationary front, squall line, warm air mass, and cold air mass. Singh (1968) pointed out

that each type of storm can produce different streamflow responses from a basin.

Atmospheric moisture other than precipitation can be a direct input of water into forest hydrologic systems. Condensation on snow or vegetation surfaces can add significantly to water contributions. (Condensation on vegetation surfaces is discussed below under "Interception Processes.") In maritime climates the vapor gradient may be toward snow surfaces on most nights through the year and during much of the winter. In California, West (1959) measured as much as 0.07 inch per day of moisture condensing on snow.

Snowfall

Accurately measuring the distribution of rain is difficult, but measuring the distribution of snow and the processes that determine it are doubly so. We do not know how to measure this input: it does not remain stationary, and additions and subtractions occur in amounts that surprise us. Rarely does snow just fall. It swirls about until it finds a surface to rest upon — usually a tree or the snow-covered ground. Depending on its path, the individual snow crystal may take only a few seconds or as much as a few weeks to reach the ground; then it may take off again into the atmosphere or to a new ground location.

The term "falling snow" is almost a misnomer; Kuz'min (cited by Miller 1964) reported that the average angle of falling snowflakes is only 4 degrees from the horizontal. Wind almost always accompanies snowfall in western forests; for example, Court (1957) found that in the Sierra Nevada only 2 percent of the precipitation fell during calm periods. Wind affects measurement of interception of rain and snow by trees.

Interception Processes

Part of the rain that enters the tree canopy adheres to leaves and branches; the tree may absorb some of this. The remainder either falls directly to the ground or flows along and drips from the leaves and branches (called throughfall), or it flows down stems to the ground (called stemflow).

The water films and drops held on the foliage and other surfaces are subject to evaporation. The amount of water that evaporates is called "interception loss." Interception loss is actually a part of total evapotranspiration, but its distinct implications in forest management necessitate discussing it separately here.

When rain falls, it wets the forest soil, but not uniformly. For some tree forms, the amount of water that drips from the branch margin is one and one-half times the average amount that reaches the ground under the tree. More than the average amount also reaches the ground at the stem. Different species perform differently, and a single tree may perform differently in different storms. A windy storm may shake droplets from limbs and foliage and thus promote a more even distribution of rain reaching the soil under the tree (Grah and Wilson 1944). A misty rain may drop most of its water on the windward margins of each tree (Kittredge 1948).

What happens to the rain intercepted by the foliage and stems? A few years ago this question had a very simple answer — it just evaporated; nobody considered complicated energy and mass relations. Now, interpretations of interception losses vary as widely as the measured amounts. Miller (1967) stated that only trivial amounts of snow can be lost by interception because there is not enough energy for evaporation. Conversely, other workers have reported interceptions of as much as 5 to 6 inches per year; losses by interception have exceeded estimated potential evaporation by a factor of 4 or 5 (Rutter 1967, Leonard and Eschner 1968, Leyton and Rodda 1972, Helvey 1967). The interpretation of interception losses has changed over the years. Even the process of interception is being questioned. Is water absorbed into leaves? Is water transferred downward through leaves ultimately to dry soil? Does the energy required to evaporate intercepted water reduce the energy available for transpiration (Murphy and Knoerr 1975)? What is the surface detention of interception? Is it represented by the regression constant in Zinke's (1967) equation

$$\text{Interception} = \text{function (storm precipitation)}$$

In misty rains and clouds, is interception negative?

Unfortunately, evaporative loss is difficult to measure (Hoover 1971). It is conventionally approximated by exposing several rain gages under the forest canopy and one or more gages in a nearby opening in the forest. The average difference in catch between these exposures (usually corrected for stemflow) is an estimate of the interception loss.

Studies of interception by mature hardwoods (Helvey and Patric 1965) and by white, shortleaf, and loblolly pines (Lawson 1967, Helvey 1967), estimated from 1-day rainfall frequencies of storms greater than 0.10 inch, have shown an annual interception of 4.3 inches by hardwoods, or 8 percent of the annual precipitation; and 9.2 to 12.1 inches for pines, or 17 to 22 percent of the precipitation, in South Carolina's Piedmont (Swank 1968). When 6-month growing and dormant seasons have equal amounts of rainfall, about 60 percent of interception on hardwoods occurs during the growing season.

In most of western North America, even where snow is the dominant form of precipitation, interception losses from rainfall are significant in spring, summer, and fall and during an occasional rainstorm in winter. Western conifers intercept about the same amount of rainfall as some eastern pine stands. Interception by old-growth Douglas-fir in Oregon in summer averaged 24 percent; during the frequent rainy periods of winter months it was 14 percent (Rothacher 1963). Price (1958) obtained almost identical seasonal values (22 and 14 percent) in a dense mixed pine-fir stand in central Arizona. During two summers, mature lodgepole pine in Colorado intercepted 30 percent of the rainfall (Wilm and Niederhof 1941).

In the drier part of the West, more widely spaced conifers intercept less preciptation. Ponderosa pine in the southern Sierra Nevada of California intercepted 12 percent of annual rainfall (Rowe and Colman 1951). In central Arizona the discontinuous canopies of alligator and Utah junipers intercepted 10 and 17 percent, respectively, of the precipitation over a 1-year period (Skau 1964). Chaparral in the Sierra Nevada and in southern California intercepts from 5 to 12 percent of annual rainfall (Hamilton and Rowe 1949).

Snow Interception

The influence of wind on the differential deposition of snow in the forest and on the transport of snow from tree crowns is readily seen. Thus, values for interception that are derived by comparing the difference between snow accumulation within the forest and in the open are known to overestimate the evaporation loss of snow held on the canopy (Hoover and Leaf 1967).

Differences between maximum snow water accumulations in the open and those under hardwood and pine stands have been used as rough estimates of snow interception; these differences suggest that the forest intercepts about the same proportion of snowfall as of rain (Sartz and Trimble 1956, Hart 1963, Dunford and Hiederhof 1944, Rowe and Hendrix 1951). In New Hampshire, snow water contents of 5.5 and 5.7 inches, respectively, were measured in 40-year-old red pine and white pine stands; 7.0 inches in a hardwood stand; and 6.8 inches in the open, equivalent to an 18 percent interception by pine (Hart 1963). In the Adirondacks, maximum snow water contents were 9.0 inches under large hardwoods and 6.9 inches under red spruce and balsam fir, or 23 percent less in the conifers (Lull and Rushmore 1960). Bringfelt and Harsmar (1974) in Sweden reported an interception loss, in a pine stand having about 50 percent canopy cover, equivalent to 26 percent of the precipitation in the open.

Mature conifers in western snowpack zones intercepted 10 to 30 percent of the snowfall; some examples are:

	Interception	Reference
	Percent	
Rocky Mountain Area		
Lodgepole pine, Colorado	23	Dunford and Niederhot 1944
Ponderosa pine, Idaho	24 to 30	Connaughton 1935
Central Sierra Nevada, California		
Ponderosa pine	10	Anderson 1976
White fir	12	Kittredge 1953
Red fir	20	Kittredge 1953
Sugar-Ponderosa pine	28	Kittredge 1953

Interception and Floods

The forest's initial influence on a flood-producing rainstorm is the amount it intercepts and stores in the canopy. This interception is a major influence only in light showers; it is most effective for brief storms, but its effectiveness dwindles rapidly as storm size increases.

Few data on the interception of flood-producing rainstorms are available; very likely interception loss in such heavy storms would be little more than the 0.2 to 0.4 inch estimated for 2-inch storms (Helvey and Patric 1965, Helvey 1967, Lawson 1967, Rogerson and Byrnes 1968). For instance, in the Douglas-fir region on the Pacific Coast, interception averaged only 4 percent of the rainfall in storms 8 inches or more (Rothacher 1963).

Interception loss, of course, reduces the amount of flood-producing rainfall that reaches the stream; but, as Hoover (1962) noted, "when it is remembered that most land areas have some type of plant growth similar to tree foliage, which intercepts rain, it is doubtful whether canopy interception by forests is of significance in reducing flood peaks." So much for the interception of rain; condensation of vapor during rainfall may be much more important during rain-on-snow storms.

Variability of Interception

Interception is a subtraction by trees or other vegetation from total precipitation and thus reduces the amount of moisture that reaches the forest floor. In certain situations trees can also trap moisture from saturated airflow. This phenomenon, found worldwide, is variously called fog drip or negative interception; it may be called horizontal precipitation if it is liquid and rime, or hoarfrost if it is solid. In the upper-slope forests of eastern Washington, for instance, horizontally intercepted moisture, forming rime and hoarfrost on lodgepole pine, amounts to 0.05 to 0.06 inch per day, and accumulates 3 to 4 inches of water during a winter (Berndt and Fowler 1969). In northern New Mexico, the amount of rime falling from an aspen canopy to the snow surface ranged from 0.02 to 0.2 inch per storm. The annual amount of moisture addition at this high-elevation site was estimated to be 1.0 inch (Gary 1972). Kittredge (1948, p. 117-118) reported that May to October fog drip under a 40-foot big cone spruce and 80-foot ponderosa pine, at 5,850 feet elevation on Mt. Wilson in southern California, was approximately 25 and 38 inches, respectively — so that total catches under the trees were 2.11 to 2.65 times the catches of precipitation gages in the open.

Forested coastal areas particularly may trap substantial atmospheric moisture. In Japan, small trees were 6 to 10 times more effective than grass or bare ground in trapping sea mists (Hori 1953 and Reynolds 1967). The front surface of the forest was about three times as effective as the top surface. Also, a tall, open, broad-leaved forest, collecting as much as 0.03 inch per hour, was almost as efficient as spruce forest. On the Oregon coast during a period of 142 days, total precipitation was 45 percent greater under a stand of Sitka spruce and western hemlock than in the open: 36 inches under the trees and 25 inches in the open. Describing this study and others, Kittredge (1948) concluded that "In regions of frequent fogs of fine misty rains . . . fog drip may at certain seasons increase the precipitation reaching the ground by amounts up to two to three times the precipitation in the open." Further substantiation came when Ekern (1964) reported on a 3-year study of a cloud-swept ridge in Hawaii; cloud drip plus rain averaged 130 inches per year under Norfolk Island pine, whereas precipitation in the open averaged only 50 inches. It is interesting to note that 30 inches of the 80-inch increase occurred during rainless days. This water was largely saved for irrigation use, for little infiltrated into the iron-pan soil in this rather unusual case. Fog drip is largely a forest-margin phenomenon, but condensation of atmospheric moisture on vegetation may be more important than has been realized. Condensation on snow was discussed earlier.

In conclusion, there is no question of difference in precipitation catch between gages under forest canopy and those in protected openings. The soil beneath dense canopies generally receives less rainfall than the soil in openings, and more snow is caught in openings and their margins. This redistribution of incoming precipitation is an important influence of the forest (Anderson 1967b, Hoover 1973, Haupt 1973). In snow conditions, part of the evaporated water may be recondensed on the snow held on foliage, and thus increase the melt and drip to snow cover beneath; part may similarly be transferred from tree to atmosphere to snow cover. In neither case does intercepted water become wholly an evaporative loss. The amount of evaporative loss from precipitation held on the canopy is in question. With rain, even the water evaporated from foliage is not entirely lost because intercep-

tion of moisture and subsequent evaporation are to some degree in lieu of transpiration. However, intercepted water may evaporate at rates much higher than transpiration rates. Nor is interception peculiar to trees. A wheat field or a 10-story building can intercept as much of the rainfall per unit area as a hardwood forest. Interception to some degree is a function of being. There would have to be exceptions; the hauli Koa of the dry side of Hawaii folds its leaves at the first drop of rain, presumably to avoid interception.

Surface Storage

The term "surface storage" includes temporary storage as surface detention—water enroute over the soil surface, water in the forest floor or litter, water ponded in depressions in the soil surface, and water held in the snowpack. Water stored in vegetation is also sometimes considered to be in surface storage.

Trees store little water internally. Mature beech and yellow birch on a good site may contain 7 to 15 thousand gallons per acre in their stems and branches at summer's end (Satterlund 1959), equivalent to a depth of about 1/4 to 1/2 inch of water; and old-growth redwood may contain as much as 150,000 gallons, an area-depth of about 5-1/2 inches.[2]

Snowpacks may contribute to surface storage both in the frozen phase and as free water. The volume and duration of detention depend on such conditions as depth of snow, air temperature, pore size, and initial free water content (Corps of Engineers 1956, Smith and Halverson 1969, and Smith 1974). Greatest detention is in the warm snowpacks of the Sierra Nevada and the Pacific slopes of the northern Rocky Mountains. Some water may be detained over winter, only to be released when the snow melts.

Snowmelt detention time is about 5 hours in the 4-square-mile Castle Creek Basin in the Sierra Nevada; measured daily runoff is equivalent to about 0.8 inch of water over the whole basin. Maximum free water in snowpacks may be as much as 18 percent of a 48-inch pack with 29 inches water equivalent; Anderson and others (1963a) reported that 5 inches of free water was detained in the pack. In a test of simulated rain on snow, 10.56 inches of water was applied to a 66-inch pack of 30 percent density; 8.9 inches of the applied water were held by the pack (Smith and Halverson 1969).

Forest cover delays snowmelt by shading and thus extends the time that the snow is held in surface storage. Conifers with persistent foliage naturally delay melt more than deciduous hardwoods. In the study of a 3-day rainfall-snowmelt flood in Oregon, Anderson (1969) estimated that forest shading reduced the melt rate by 40 percent (and flood flow by 10 percent). Studies of two California rain-on-snow floods gave similar results (Anderson 1970a).

Though snow under forest cover melts later and persists longer than snow in the open, it may melt more rapidly once it begins. This happens because melting occurs later in the season when temperatures may be much higher. A mixture of forest and open areas on a watershed may promote snowmelt at different times and thus reduce streamflow peaks. Topography also desynchronizes melting—snow on southerly aspects may disappear before much of the snow melts on northerly aspects.

Surface storage of water generally affects the rate of runoff more than the water yield. Surface detention is clearly a significant phenomenon in the hydrology of snow-zone forests. The paths and flow rates of much of this detained water are related to energy disposition within the forest environment, to soils and to local topography; the management of these forests may be effective or not, depending on how these paths, rates, and amounts of detention are modified.

Water stored on the surface of the soil eventually leaves the surface as overland flow, evaporates to the atmosphere, or infiltrates into the soil.

Almost all of the precipitation that reaches the ground sooner or later either infiltrates into the soil or leaves the surface as overland flow, often ambiguously termed surface runoff. The amount of overland flow is largely determined by the relation between infiltration capacity, storage opportunity, and rainfall intensity. Thus those forest practices and conditions that severely limit the infiltration capacity of the soil increase overland flow.

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[2] Zinke, Paul J., and Peter E. Black. 1964. Soil moisture observations around old-growth redwoods. (Paper presented before the Hydrology Section of the American Geophysical Union, Western Regional Meeting, Seattle, Washington, Dec. 1964.)

Infiltration Processes

Infiltration capacity is the rate at which water can enter the soil surface, and is usually specified for a particular condition of rainfall or snowmelt, soil frost, soil-water content, and wettability.

How is infiltration capacity measured? A wide variety of infiltrometers has been invented; they all use either artificial rainfall or surface flooding of relatively small areas. In general, their determinations serve only as indexes of broad differences of surface conditions which may or may not affect infiltration processes under natural rainfall in forests. Another technique involves analysis of hydrographs, in which rapid rises in the streamflow hydrograph are assumed to have resulted from rainfall rates that exceed infiltration capacity.

East or West, rainfall in the undisturbed forest rarely produces overland flow that results solely from limited infiltration capacity. Where storage capacity remains, the forest floor developed under uncut, unburned, and ungrazed forest readily absorbs and transmits downward the water from even extreme intensities of rainfall. Because of the persuasive logic of the infiltration concept of streamflow generation, which applies to many nonforest areas, even forest hydrologists were slow to recognize that overland flow is virtually absent from the mature undisturbed forest. Realization of this fact grew from reports by Hoover and Hursh (1944) for North Carolina forests, of Anderson (1962b) for California, Rothacher (1965a) for Oregon, Muller (1966) in the Allegheny Plateau of New York, Hewlett and Hibbert (1967) confirming the North Carolina observation, Yevjevich (1968) for Colorado, and Tsukamoto (1966a) for Japanese forests. From these general conclusions and many specific reports, the admonition of Hewlett and Hibbert (1967) seems appropriate: "In the case of forest land begin with the assumption that all flow is subsurface flow until there is evidence otherwise."

A test in southeastern Alaska provided the ultimate demonstration: Over a 30-day period more than 400 inches of water was sprinkled over a steep brush-covered slope without producing overland flow; about two-thirds reached the channel as subsurface flow; the remainder was lost to deep seepage or evapotranspiration (Patric and Swanston 1968).

Overland flow seldom occurs in the forest even during flood-producing rainfall. For instance, field examinations following the flood caused by Hurricane Diane in August 1955 revealed very little overland flow in the Poconos of Pennsylvania or in New England. Signs of such flow were found only on slopes greater than 50 percent at points where, presumably, subsurface flow intersected the surface.[3] Of course, local areas have overland flow, produced chiefly by roads, skid trails, rocky areas, and many small areas where infiltration is impaired.

Infiltration capacities of forest land not only exceed rainfall intensities; they may, for example, also absorb overland flow from adjacent natural rock outcrops, agricultural lands, and roads. In the driftless area of southern Wisconsin, most overland flow from open fields on ridges infiltrates into the forest slopes below and does not reach the valley. Over a 4-year period, 187 storm runoffs of 10 cubic feet or more were measured at gages above forest boundary; only 18 of these runoff volumes were recorded by gages in the valley below the forest. Overland flow from the upland fields infiltrated into the forest floor and seeped into valley bottoms (Curtis 1966). Packer's (1967a) study of the ability of the forest floor to absorb runoff from roads showed that the width of the protection strip required to keep runoff and sediment out of streamflow depends on several soil, cover, and topographic factors.

There are sure to be exceptions to any generalization in forest hydrology. Overland flow may occur in the forest under some special conditions. Recent research in Nevada, California, and Arizona has shown that sometimes there is a nonwettable soil layer 1/2 to 1 inch below the surface, formed by decomposition of organic matter (DeBano and others 1967, Cory and Morris 1968, Scholl 1975). Forest fire may cause the development or intensification of such a layer. Although the phenomenon has been observed during small-scale tests when water was artificially applied to undisturbed forest soils under red fir, its extent and importance in unburned soils have not been demonstrated because once wetted, these same soils showed

[3] Varney, G. L. 1955. Some aspects of forest land behavior during the floods of August 1955. (Report on file, Northeast. For. Exp. Stn., Upper Darby, Pa.)

high infiltration rates. Nonwettability of burned areas is discussed later.

There are occasional reports of overland flow across a shingle-like cover of hardwood litter (Pierce 1967, Hoover 1962). This is a local phenomenon, and the flow infiltrates the soil within a short distance. Whipkey (1969) observed several such overland flows in a hardwood forest where simulated rainfall was applied at intensities of 5 to 30 inches per hour for periods of 60 to 150 minutes.

Evidence of apparent overland flow, such as small piles of leaves and twigs, and even exposure of the mineral soil, can often be noted in smaller draws or the drainageways between microridges. Closer observation usually shows that water infiltrated the upper slope and reappeared downslope or in the draw. This happens not because of limited infiltration capacity but because of limited capacity for storage and percolation and channel expansion; no amount of improvement in infiltration capacity at the point where the rain fell will mend it. Subsurface storage and detention become the dominant hydrologic processes.

Watershed Storage

The storage capabilities of a watershed largely determine what proportion of a flood-producing rainfall will reach any damage point downstream and at what rate. In its broadest sense, storage includes all aspects of retention and detention: interception; surface storage on the soil; storage in the vegetation, soil, and underlying rock; and storage in the channel. Interception and surface storage have already been discussed; detailed discussion of channel storage is beyond the scope of this report.

Soil-water storage accounts for the water from the time it infiltrates the soil until it leaves to go to groundwater, to streamflow or other surface water, or to the atmosphere by evaporation from the soil surface or transpiration from foliage.

Storage is of two types, detention and retention. These are relative terms, detention denoting that moisture in the soil is detained only temporarily as it makes its way towards groundwater or streamflow, retention being that water retained, against gravitational forces, and later discharged to the atmosphere. Substitution and exchange, which occur among all components of storage and delivery, impose problems of measurement.

Measurements of soil water range from laboratory analysis of soil samples,[4] through such physical indicators of field water content as resistance, capacitance, and "adsorption" of neutrons, to inference of soil water from hydrograph analysis. Tracing with chemicals and tritium has added some information about the paths and rates of flow within the soil.

Detention storage, drained by gravity, and retention storage, held against gravity, have often been equated to the amounts greater and less than field capacity, respectively. Field capacity has been defined as the amount of water held in a soil after excess gravitational water has drained away and after the downward movement has materially decreased (Veihmeyer and Hendrickson 1931). More than 25 years ago, Edlefson and Bodman (1941) reported that the simple drainage of soil/water to moisture contents less than normal field capacity was an important source of long-term discharge of water. More recently, Hewlett (1961) and others have demonstrated that slow drainage of soil moisture in the range of field capacity may be the source of a large proportion of the base flow of headwater streams.

Forest soils are generally less dense than similar soils not covered by forest and may have greater capacity for detention but less capacity for retention. Thus, for Coastal Plain soils of Mississippi the drainage capacity (total pore volume minus volume held at 1/3 atmosphere tension) for surface forest soils has been found to average 35 percent by volume, contrasted to 20 percent for old fields and pastures. Retention capacities (difference in volume between the amounts held at 1/3 and at 15 atmospheres of tension) averaged 14 percent for surface soils of the forest and 17 and 14 percent for old-field and pasture soils (Broadfoot and Burke 1958). In forest soils, the density, the retention capacity, and the total volume of stored water are highly affected by the amount of

[4] In laboratory tests of soil, water held against gravitational forces (retention capacity) is taken as the amount held against a tension of 1/3 atmosphere. Water held too tightly for extraction by transpirational forces is taken as the amount held against a tension of 15 atmospheres. Maximum storage is taken as the water content when all pores are occupied. Detention storage capacity is taken as the water content when all pores are occupied. Detention storage capacity is taken as the difference between maximum storage and retention capacity.

Table 1–*Representative soil depths of forested watersheds*

Watershed location and reference	Soil depth		Subsoil weathering[1]
	Range	Average	
	Feet	*Feet*	
(1) Northern United States	2 to 8	4.7	–
(2) Mid-South United States	–	6	-
(3) N. Sierra Nevada, Calif.	15+		To 70 ft
(4) Northern Coast, Calif.	4 to 5	–	Yes
(5) Hubbard Brook, N.H.	–	5	–
(6) Fernow, W. Va.	3 to 5	-	–
(7) Coweeta, N.C.	3 to 6	-	–
(8) H. L. Andrews Exp. Forest, Oreg.	3 to 6	–	Yes
(9) San Dimas Exp. Forest, Calif.	–	<2.5	Yes
(10) Fraser, Colo.	1 to 2	–	To 14 ft
(11) Central Sierra Nevada, Calif.	1 to 9+	3.5	

[1] Dash indicates no data available; "yes" indicates weathering occurs but depth is variable.

(1) U.S. Dep. Agric. 1952
(2) Zahner 1956
(3) Ziemer 1968
(4) Gardner 1958
(5) U.S. Dep. Agric. Forest Serv. 1964b
(6) Reinhart and others 1963
(7) U.S. Dep. Agric. Forest Serv. 1957
(8) Rothacher and others 1967
(9) Rowe 1963
(10) Love and Goodell 1960
(11) Anderson and Richards 1961

organic matter in the soil. Additions of from 1.2 to 10 percent of organic matter have increased the amount of water retained in clay soils by 34 percent, in fine sand by 150 percent, and coarse sand by 780 percent (Feustel and Byers 1936). Coile (1938) found similar increases. Organic matter decreases soil density, and therefore has a direct effect on soil depth.

Depth of forest soils throughout the country varies widely but generally ranges between 2 and 8 feet. Some reported soil depths to parent material, or to impermeable layers, are summarized in *table 1.* The mid-South and the Pacific Northwest have deeper forest soils. For the upland pine forests of the mid-South, Zahner (1956) considered the upper 6 feet of surface soil to be the effective root zone. In deep soils and under intense climatic stress rooting is deeper. At 2900 feet elevation in the Sierra Nevada, Ziemer (1968) found summer depletion under pine to depths greater than 15 feet. In the redwood—Douglas-fir region of northern California, soils as deep as 4 to 5 feet rest on weathered, shattered, water-holding parent materials (Gardner 1958) which may furnish water to the trees during periods of soil moisture stress.

The maximum opportunity for soil-water storage that the forest can generate at any one point is essentially the difference between field maximum and field minimum moisture contents throughout the rooting depth. Several of these maximums, derived from soil-water studies, are given in *table 2.* They range from 2 to 23 inches and, according to soil texture, from 1 to nearly 4 inches per foot of depth. The maximum soil-water depletion measured (Ziemer 1968) was 22.6 inches for an isolated pine in the Sierra Nevada.

Retention storage capacity varies greatly, especially with soil depth and texture. Although many forest soils are often classified as shallow (from 5 or 10 to 20 or 30 inches deep), they can retain several inches of water after prolonged drying. However, when flood rainfall occurs, the first extraction from rainfall at any one point depends not so much upon the capacity as upon the amount of drying since the last significant rainfall, i.e., the retention opportunity.

A watershed's maximum opportunity for soil-water retention can be estimated from the difference between storm rainfall following a prolonged drying period, and storm discharge. Estimates differ widely between Eastern and Western watersheds. Some characteristic values are:

	Maximum storage opportunity	*Condition*	*Reference*
	Inches		
Location:			
Northeast	4.0-4.5	During major storms	Hoyt and Langbein (1955)
East	1.5-2.5	During major storms	Hoyt (1942)
	4.0-5.5	After long drying	Reinhart (1964a)
N. Sierra Nevada	20	After summer drying	Anderson (1963)
	8	After mid-winter drying	Anderson (1963)
San Gabriel Mts., Calif.	22	After long drying	Rowe[5]

Opportunity for retention storage varies seasonally in the East. When the soil has been recharged by autumn rainfall after the growing season, retention opportunity is at a minimum until spring. Frequent rainfall during the growing season in the East can severely limit the retention opportunity for flood rainfall. For example, estimates of maximum retention opportunities on the Fernow Experimental Forest in West Virginia were based on daily water-budget estimates over 11 growing seasons (April-November).[6] Even in the dryest season (1957), for the 10-inch retention capacity, opportunity was more than 2 inches on only 61 days of the 244-day season; the mean for the season was 1.3 inches. The mean retention opportunity in 1956 (a wetter season) was only 0.25 inches.

[5] Rowe, Percy B. 1955. Rainfall disposition by hydrologic years 1938-39 through 1952-53, Volfe Canyon, Watershed IX, San Dimas Experimental Forest. (Unpublished report on file, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.)

[6] Unpublished report, Northeast. Forest Exp. Stn., Parsons, West Virginia.

Table 2–*Maximum soil-water storage under selected forest stands*

Location and forest cover	Sampling depth	Soil-water storage
	Feet	*Inches*
(1) New Jersey Coastal Plain		
Shortleaf pine	10	8
(2) Southeastern Ohio		
Oak	3.3	7 to 9
(3) Western North Carolina		
Appalachian hardwoods	7	11
(4) Piedmont of South Carolina		
Loblolly pine	5.5	5
Loblolly pine-hardwood	5.5	9
(5) Missouri		
Oak-hickory	3.3	9
(6) Southern Arkansas		
Southern red and post oaks, sweetgum; loblolly and shortleaf pines	4	12
(7) Texas		
Post and blackjack oaks	2	5
(8) Cascades, Oregon		
Douglas-fir, western hemlock	2 to 6	2 to 23
(9) Central Sierra Nevada, Calif.		
Red fir (subalpine)	4 to 10	8 to 16
(10) Southern Sierra Nevada, Calif.		
Woodland chaparral	3	7
Ponderosa pine	6	11
(11) San Dimas, Calif.		
Mixed chaparral	5	11

Compiled as follows:
(1) Lull and Axley 1958
(2) Gasier 1952
(3) Helvey and Hewlett 1959
(4) Metz and Douglass 1959
(5) Lull and Fletcher 1962
(6) Moyle and Zahner 1954
(7) Koshi 1959
(8) Rothacher and others 1967
(9) Knoerr 1960
(10) Rowe and Goldman 1951
(11) Rowe and Colman 1951

Farther south on deeper soils, opportunities for storage are much greater. In the Piedmont of South Carolina, for instance, daily soil-water measurements for 3 years under a 50-year-old shortleaf pine—hardwood stand (Metz and Douglass 1959) recorded median storage opportunity for two soil-water seasons: January to April, about 2 inches and May to December, about 6 inches.

In major river basins on the west side of the Sierra, the soil-water deficit in the fall has been estimated to range from 4 to 10 inches. Rock storage varies from negligible amounts in granite batholith to 45 inches or more in highly fractured igneous rock and unconsolidated alluviums (Anderson 1962b). The retention for whole large

watersheds has exceeded 20 inches in early winter storms and 8 inches in succeeding midwinter flood-producing storms (Anderson 1963). When compared with the yearly evapotranspiration loss (Rothacher and others 1967), data from Dyrness (1969) on the maximum storage opportunity at the end of summer in the H.J. Andrews Experimental Forest indicate that the opportunity must be restored several times during the year to account for a loss of as much as 33 inches.

These measurements of retention storage opportunity and recovery of retention capacity, in one case in the middle of winter and in the other case repeatedly throughout the year, cast some doubt on the validity of the simple concept of maximum retention storage in these watersheds. This concept is the familiar single linear reservoir with a single spillway whose discharge is proportional to the storage; however, Sugawara (1967) showed that multiple reservoirs in series and parallel, with complex outlets to each other, are necessary to simulate streamflow hydrographs; equally complex analogues may be needed to explain adequately the performance of forests in flood prevention and streamflow yield generally. Thus, maximum retention storage may never be achieved in some of these watersheds, for some areas may always have retention capacity that does not become full because of the lack of input water or because of input channels which require heads of longer duration. On some watersheds, near-maximum retention opportunity may be achieved only after a long drought; on others, only when water is available for percolation throughout the year will some of this excess retention storage be filled. The nature of these multiple reservoirs and their different input and output channels controls storage and its product, subsurface flow.

Subsurface Flow

Subsurface movement of detained water on forested slopes has been widely studied in recent years, yet we still know little about its rates of movement. Water entering the surface soil sometimes flows downward until it reaches a layer of different texture. Then it flows downhill along this interface until it finds opportunity for further penetration. Such lateral flow has been measured and described by Whipkey (1969), McDonald (1967), Minshall and Jamison (1965), and Smith (1972). At other times the flow is simple drainage from the lower slope reaches, such as Hewlett and Hibbert (1967) reported, rather than flow occurring at the top of the B horizon or at a layer of finer soil texture. Ragan's analysis (1968) showed that only a small area of the forested watershed he studied contributed flow to the storm hydrograph. The contributing area, a function of storm duration and intensity, was not uniformly distributed along the channel, but was localized in only a few zones. This subsurface drainage, together with rainfall on saturated soils and on water surfaces, accounted for the occasional very high floodflows discharged from upland forest watersheds in the absence of widespread appreciable overland flow. Martinec (1975), from a study of the tritium content of subsurface flow, concluded that this flow included some water that had been in subsurface storage for several years.

Despite the considerable progress in both the conceptual and the experimental studies of subsurface flow, the rates of flow and the spatial distribution of the flow paths are basically unmeasureable. Techniques measuring these flows must be developed because knowledge of these rates and distributions are crucial to understanding and predicting water use by vegetation, zones of saturation and soil instability, and the potential of parts of any watershed to generate flood peak flows.

Peak Flows

Subsurface flow in the forest can produce substantial peak flows in streams. Thus, completely or partly forested watersheds have produced floods periodically *(table 3).* Hursh (1943) reported a peak of 167 csm ($ft^3/s/mi^2$) from a small, forested, high-elevation watershed in western North Carolina during a low-intensity storm in which infiltration was not limiting. In New Hampshire, in October 1959, peak discharges from two well-forested watersheds of 105 and 39 acres were 451 and 462 csm respectively, during a 7-inch storm; maximum measured 1-hour rainfall was just over 1 inch.[7] Storm flows, calculated by the procedure of Hewlett and Hibbert (1967), were 76 percent of rainfall for the larger watershed and 85 percent for the smaller. From much larger watersheds (45 to 143 square miles) peak flows of 126 to

[7] Storm peaks and storm damage of October 23-25, 1959, Hubbard Brook Experimental Forest and White Mountain National Forest, New Hampshire. (Report on file at Northeast. For. Exp. Stn., Durham, N.H.)

Table 3—*Record peak flows and percentage of forest cover for watersheds approximating 25, 100, 500, and 1000 square miles*

Stream	Station	Drainage area	Peak flow	Forest cover
		Mi²	*Ft³/s/mi²*	*Percent*
	North Atlantic Slope Drainage			
Ellis River	Jackson, N.H.	28	529	100
Rondout Creek	Lackawack, N.Y.	100	267	80
Rapidan River	Culpepper, Va.	465	125	53
N. Branch Potomac River	Cumberland, Md.	875	102	82
	South Atlantic and Western Gulf of Mexico Drainage			
Morgan Creek	Chapel Hill, N.C.	27	1110	61
Henry Fork	Henry River, N.C.	80	391	88
Yadkin River	Wilkesboro, N.C.	493	324	90
Rocky River	Norwood, N.C.	1370	113	55
	Ohio River Basin			
Elk Creek	Elk Park, N.C.	42	655	67
Watauga River	Sugar Grove, N.C.	91	560	62
Watauga River	Butler, Tenn.	427	168	64
Cheat River	Rowlesburg, W. Va.	972	129	87
	Pacific Slope Basins in California			
San Antonio Creek	Claremont, Calif.	17	1267	63
W. Fork San Gabriel River	Camp Ricon, Calif.	102	334	100
Los Angeles River	Los Angeles, Calif.	512	131	28
N. Fork American River	Rattlesnake Branch, Calif.	999	95	90
	Pacific Slope Basins in Washington and Upper Columbia Basin			
N. Fork Skokomish River	Hoodsport, Wash.	60	388	75
Wynooche River	Montesano, Wash.	105	238	90
Skykomish River	Gold Bar, Wash.	535	148	78
Sauk River	Sauk, Wash.	714	96	77

Source: Linsley and others 1949

more than 300 csm were registered. Corbett and others (1975) studied flow from a 20-acre watershed in Pennsylvania where artificial rainfall was applied to three areas: ridge, midslope, and near-channel. Quickflow dominated the flow regime, being 65 to 85 percent of the total flow, irrespective of the part of the watershed to which the simulated rainfall was applied.

Subsurface flow from low-intensity, long-duration rainstorms in Oregon may have maximum rates of runoff that are as much as 80 percent of the average rate of measured rainfall for the preceding 12 to 24 hours. For shorter durations, the maximum rainstorm of record (12.5 inches in 3 days, 1.9 inches in 6 hours) on a 237-acre watershed of Douglas-fir and western hemlock produced a peak of 139 ft³/s/mi² (Rothacher and others 1967). This peak runoff is the equivalent of only 0.22 inch per hour, about two-thirds of the *average* rainfall rate of 0.32 inch per hour in the 6-hour period. The modifying influence of the forested watershed on flood peaks from small experimental watersheds was strikingly illustrated in the storm that produced the Rapid City flood on June 9, 1972. Although prior rainfall was "apparently enough to fill available soil storage capacity and cause flow to respond almost immediately" to the additional high-intensity rain of 2.12

to 3.25 inches in 1 hour (Orr 1973), the records show that maximum hourly flow never exceeded about 15 percent of the maximum hourly rain. Tsukamoto's study (1975) of the role of forest floor litter in reducing peak flows showed that removal of litter increased peak flows from storms of less than 4 inches by 168 percent.

However, a high-elevation, steep, completely forested watershed without appreciable overland flow may produce greater volumes of stormflow per unit rainfall than many pastures and cultivated areas at lower elevations (Hewlett and Hibbert 1967). In the Northeast, generally, the greater the proportion of watershed that is forested, the greater the streamflow (Lull and Sopper 1967). These high flows, and the others tabulated above, do not show a negative "forest influence" but rather the integrated influence of the forest-occupied environment — with steeper topography, shallower soils, and more rain.

Erosion and sedimentation are discussed in detail elsewhere in this report. We must recognize here, however, that transported sediment stemming from erosion bulks flood flows and may increase flood stages. Even more important is the fact that deposits of sediment in stream channels reduce the carrying capacity and increase the frequency and severity of overbank flooding. Dirty flood water is more damaging than relatively clean water, and sediment left by a flood can cause a substantial part of its total damage. It follows, then, that as forest cover inhibits erosion, it significantly contributes to preventing flood damage.

Evapotranspiration creates storage opportunity in the soil so may affect floods and soil and slope stability, but also withdraws potential water supply.

Evapotranspiration

Evapotranspiration from the forest is powered by solar energy. It includes the evaporation of rain and snow intercepted by the canopy, the vaporizing of water that reaches the leaf surface in the transpiration, and the evaporation of moisture from bare areas, the wetted forest floor, or snow cover.

Transpiration

Transpiration accounts for most of the vaporization from the forest—perhaps 80 percent in hardwoods and 60 percent in conifers. The remainder is evaporation from rainfall and snowfall intercepted in the canopy, from snow and wet litter on the forest floor, and from the soil beneath. Transpiration is difficult to measure and is most often estimated indirectly from the difference between precipitation and streamflow during selected time periods, or estimated from a water budget developed from periodic measurements of soil water and precipitation, or estimated from aerodynamic or energy budgets.

Radiant energy is primarily responsible for evapotranspiration. The energy used is drawn from net radiation, which is the difference between incoming and outgoing solar and thermal radiations. Net radiation energy is used to heat air, soil, water, and vegetation; it is also used in photosynthesis, respiration, and evapotranspiration. By far the greatest portion of the energy is used in evapotranspiration and in heating the air. Evapotranspiration from thoroughly wetted forest soil is limited by the energy supply; during soil drought and high climatic stress evapotranspiration is primarily limited by the water supply, but the trees exercise some physiological control (Lee 1967).

Powered by radiant energy and dependent on available moisture, forest evapotranspiration tends to be greatest in warm and wet climates and least in cold, dry ones. This is indicated in the several comparisons of potential evapotranspiration (Thornthwaite and Mather 1957) for points centrally located in major forest types *(table 4* and *fig. 3)*.[8] The longleaf-slash location, the warmest, has the greatest potential; the lodgepole pine location, the coldest, has the least potential; and the more humid the climate, the more likely it is that actual evapotranspiration will approach the potential. Similar average potentials are a feature of such diversely located types as spruce-fir in Maine (21 inches) and ponderosa pine in Arizona (23 inches), of maple-birch-beech in New York (26 inches) and redwood in California (25 inches).

Slope and aspect combinations markedly affect the amount of solar radiation received on any given area and thus markedly affect evapotranspiration. In studying these relationships, Lee (1964), describing watersheds in terms of their average exposure and potential insolation, found strong negative correlation between the radiation indexes and annual streamflow from adjacent basins. He

[8] Potential evapotranspiration is an estimate of maximum possible evapotranspiration, the evapotranspiration that would occur if water were fully available.

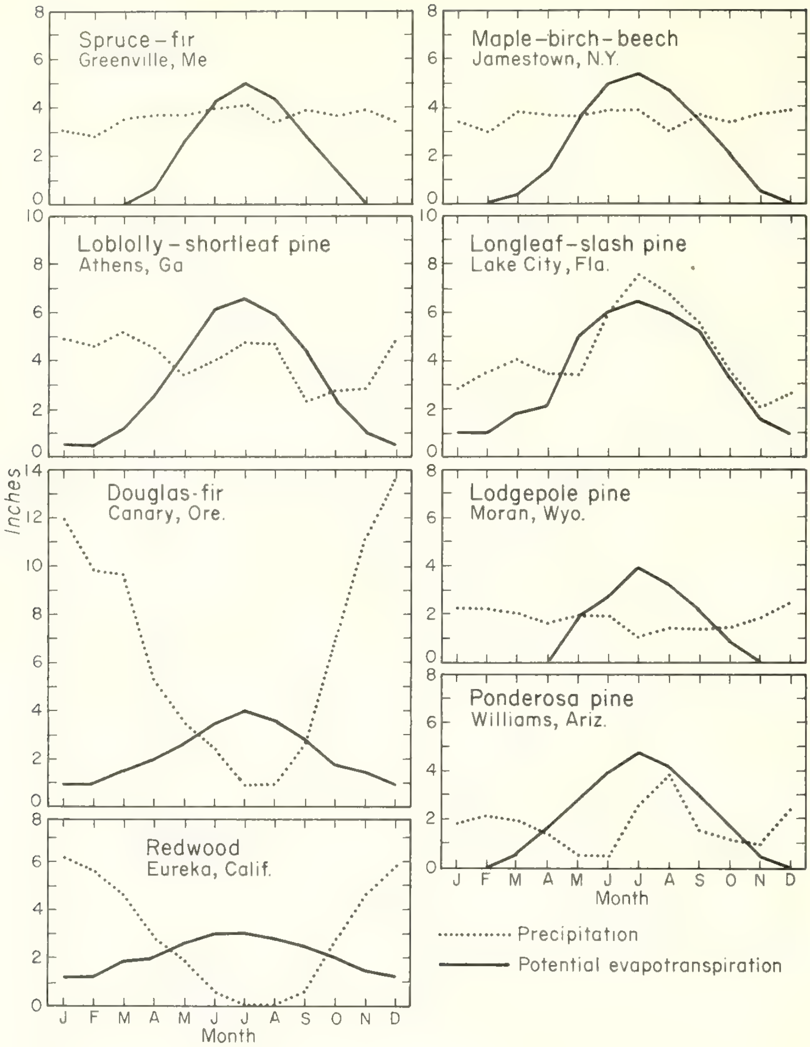

Figure 3—Mean annual potential evapotranspiration and precipitation at points centrally located in some major forest types.

Table 4—*Mean annual potential evapotranspiration, precipitation, and air temperature at points centrally located in selected major forest types*

Forest type	Location	Potential evapo-transpiration	Precipitation	Air temperature
		Inches	*Inches*	*°F*
Longleaf-slash pine	Lake City, Fla.	42	51	69
Loblolly-shortleaf pine	Athens, Ga.	36	48	63
Maple-birch-beech	Jamestown, N.Y.	26	43	49
Douglas-fir	Canary, Oreg.	26	79	52
Redwood	Eureka, Calif.	25	36	52
Red fir	Teakettle, Calif.	25	44	43
Ponderosa pine	Williams, Ariz.	23	21	49
Spruce-fir	Greenville, Maine	21	43	40
Lodgepole pine	Moran, Wyo.	15	21	34

assumed these differences to be attributable to differences in evapotranspiration. Because of differences in the energy they receive, slopes and aspects differ markedly in potential evapotranspiration. In southern Missouri, for instance, where the soil-water storage capacity is 10 inches, the calculated moisture deficit on a horizontal surface for a normal year was 3.9 inches; a 40° north slope had a deficit of 1.9 inches, and a 40° southwest slope had a deficit of 5.9 inches (Nash 1963). These studies did not consider the influence of advected energy. In attempting to use space- and time-integrated air temperatures, Chang and Lee (1969) used chemical sensors to integrate temperature with soil information and seasonal responses of plants. They believed that using this technique enabled them to prepare better estimates of water balance.

The amount of water evapotranspired from mature forests also depends on the amount of moisture available in the soil, which in turn is largely a function of soil texture and depth, and, of course, climate. With some exceptions (Anderson and Gleason 1960, Ziemer 1968, Rothacher and others 1967) the upland forest, regardless of type, receives sufficient radiant energy during the growing season to deplete most if not all of the available moisture. For example, in Arkansas (Moyle and Zahner 1954), South Carolina (Metz and Douglass 1959), Michigan (Urie 1959), and Colorado (Brown and Thompson 1965), the amounts of soil water withdrawn under conifers and hardwoods during the growing season were very similar, almost equally depleting moisture. Annual evaporative losses from white pine stands at Coweeta were greater than from hardwoods (Helvey 1967). This was ascribed to greater interception by the persistent foliage of the pine and not solely to greater depletion of soil water. The differences in the many phenological characteristics of individual tree species as they influence water use are as yet little known.

To some degree the trees themselves control transpiration—by controlling water loss through the stomates, which cover from 1 to 3 percent of the leaf surface. With an average density of 100 to 300 stomates per square millimeter, this loss can approach the rates of evaporation from free water (Slavik 1965). Opening and closing of stomates are controlled primarily by the water content of the leaf, but increases in light and rising temperatures also stimulate opening. The rates of water loss at specific stomatal openings are not constant but depend on atmospheric conditions. Lee (1967) suggested that careful study of the microstructure of leaf types and of their abilities to control transpiration seasonally would provide a rational basis for managing vegetation to increase water yield. Other investigators are far less optimistic (Idso 1968, Van Bavel 1968).

One influence on the stomatal mechanism is the available energy, which is determined in part by such forest characteristics as color, size, phenology, and vigor. The darker the forest, the lower its albedo; i.e., less of the incoming solar radiation is reflected. For example, summer albedos for birch-maple and white pine stands in New Hampshire were 0.17 and 0.14, respectively (Federer 1968); the pine had 3.6 percent more energy available for evapotranspiration. According to one estimate, darkening of the foliage by wetting can reduce albedo by 40 percent (Goodell 1967, citing Scholte Ubing). Stands having taller trees usually capture more radiant energy and have a lower albedo. Phenological differences are another factor: in Michigan, for instance, red pine stands rapidly deplete moisture in April and May, whereas hardwood stands do not begin until June, when their leaves are fully developed (Urie 1959). Finally, there is some evidence that the stage of growth influences water use. Black (1967) found that second-growth redwood stands depleted soil moisture more rapidly than old-growth stands, and Knoerr earlier (1960) reported that young red fir depleted soil moisture more than older stands. Kittredge (1948) showed that trees reach the culmination of their growth rate and their maximum leaf surface in fully stocked stands at between 15 and 60 years, and that transpiration is related to area of foliage.

Though we are accustomed to thinking that growing and dormant seasons control transpiration, even in some temperature climates—e.g., along the Pacific Coast—a true dormant season may not exist. Even when snow is on the ground, daytime air temperatures may reach 55 °F; tests of water transport through the trunks of pines, using heat pulse velocity and radioactive tracers, have indicated that sizable quantities of water are transpired during winter, spring, and early summer (Swanson 1967, Smith 1972). Such use may help explain why evapotranspiration in Douglas-fir forests (Rothacher and others 1967) is three to four times the maximum depletion of retention storage reported by Dyrness (1969), and may explain how 8 inches of soil moisture deficit

could have been created in winter in the Sierra Nevada (Anderson 1963).

Evaporation

Evaporation from the forest floor or from snow surfaces can add significantly to transpiration as an evaporative loss at some places. Evaporative losses from the forest floor vary greatly. Aldon (1968) reported losses amounting to as much as 1.09 inches of moisture during a 30-day period of summer thunderstorms. Similarly, Rowe (1955) reported that about 0.1 inch of water was stored per inch depth of forest litter. In a 4-year period when annual precipitation averaged 49 inches, the water evaporated from the forest floor ranged from 3.0 to 5.2 percent of the precipitation for floor depths of 1 inch to 3.6 inches. Litter on the forest floor may range from negligible amounts to more than 20 tons of oven-dry material per acre (Kittredge 1948). The loss from 1 inch of litter was about 15 times the storage capacity; from 3.6 inches it was about 7 times the storage capacity. Total replenishable storage deficit was greater for bare soil than for soil covered by 1-1/4 inches of pine litter; the bare soil lost 10.7 inches of water per year by evaporation; soils covered by 1/2 inch or more of litter lost about 7 inches (Rowe 1955). In the Appalachians, evaporation of moisture from litter of hardwoods and white pine is only about 2 inches (Helvey and Patric 1965, Helvey 1967).

Evaporation of snow under the canopy can be slow: in a 3-year study, annual evaporation from January to as late as June under a dense lodgepole pine-red fir stand in the central Sierra Nevada amounted to only 0.4 to 1 inch of water (West 1962). In the southern Sierra Nevada, the 3-year average annual evaporation from snow was zero within the red fir forest, 0.5 inch in small forest openings, and 1.8 inches in large open areas (Anderson and Richards 1961). Intercepted snow in trees may evaporate as much as three times faster than snow on the ground because of the much lower albedo of the snow-foliage moisture (Leonard and Eschner 1968).

Water Yield

The water yield of an area is that part of precipitation that is not used on the watershed. Water used by the forest is derived from the combination of dormant season precipitation, soil water stored during the dormant season, plus summer rainfall. The minimum annual requirement of moisture for forest growth is about 20 inches of precipitation; from this the forest transpires about 15 inches. In the precipitation-evapotranspiration-water yield relationship, evapotranspiration is the most nearly constant element; each year it subtracts what the forest "needs" from total precipitation, which is variable. The residue, water yield, is the most variable element in the cycle; it includes both streamflow and groundwater recharge.

Groundwater

Water that seeps through the soil mantle and adjacent rock strata may move directly to a stream or into a groundwater aquifer. Most of the water that goes into aquifer storage eventually turns up as streamflow (though perhaps below the point where a particular watershed is gaged) or is utilized from wells.

Most research on small watersheds has necessarily been conducted in areas where the true groundwater component is relatively small. However, several European studies show the effects of forests on groundwater. In one study, clearcutting a stand that had 100 m^3/ha of pine caused the water level to rise as much as 40 cm (16 inches) (Heikurainen 1967). Thinning also raises the water level; the amount of rise depended upon the intensity of thinning. Mustonen and Seuna (1971) reported increased streamflow of 0.9 inch per year from peatlands after clearcutting of trees.

Streamflow

Average annual streamflow from major forest regions varies throughout the country from 5 to 50 inches, and monthly amounts vary from near zero to 25 percent of the annual total. Records of annual and monthly streamflows from eight forested experimental watersheds show some important characteristics (*table 5* and *fig. 4*). Differences in streamflow result mostly from the climatic differences among major forest regions. Maximum annual precipitation of 94 inches is about 4 times the minimum value, which is 22 inches; streamflow, as would be expected, varies more—from 61 to 2 inches; so the ratio of the maximum to the minimum is more than 30.

Table 5–*Mean annual precipitation and streamflow for selected forested watersheds*

Location	Forest cover	Area	Mid-area elevation	Precipitation	Streamflow	Precipitation less streamflow
		Acres	*Feet*	*Inches*	*Inches*	*Inches*
Hubbard Brook Exp. Forest West Thornton, N.H. (Watershed 3)	Northern hardwoods	105	2,050	48	27	21
Fernow Exp. Forest Parsons, W. Va. (Watershed 4)	Central Appalachian hardwoods	96	2,500	58	24	34
Coweeta Hydrologic Lab. Franklin, N.C. (Watershed 18)	Southern Appalchian hardwoods	31	2,700	72	36	36
Marcell Exp. Forest Grand Rapids, Minn. (Watershed S-2)	Bog black spruce	24	1,385	31	7	24
Fraser Exp. Forest Fraser, Colo. (Fool Creek)	Lodgepole pine, spruce-fir	714	10,400	22	12	10
Sierra Ancha Exp. Forest Ariz. (Middle Fork)	Ponderosa pine–white fir	521	7,150	32	3	29
Three Bar Exp. Watersheds Ariz. (Watershed D)	Chaparral	80	4,250	27	2	25
H. L. Andrews Exp. Forest Blue River, Oreg. (Watershed 2)	Douglas-fir	149	2,500	94	61	33

Fifty to 65 percent of precipitation appears as streamflow in northern hardwoods, Appalachian hardwoods, lodgepole pine-spruce-fir, and Douglas-fir; slightly more than 20 percent in bog black spruce in Minnesota, and less than 10 percent in ponderosa pine-white fir and chaparral in Arizona (*table 5*).

Monthly precipitation and corresponding montly streamflow differ widely among regions (*fig. 4*). The West and Southwest show the greatest seasonal variations. Streamflow from rainfall and snowmelt exceeds monthly precipitation in northern hardwoods during April, and in lodgepole pine-spruce-fir during June. Uniform winter streamflow in the lodgepole pine-spruce-fir, bog black spruce, and ponderosa pine-white fir types attests to cold winters with little snowmelt; in the chaparral, low streamflow is due to low monthly precipitation. The Appalachian hardwoods produce high winter and spring flows, mostly from rainfall, followed by greatly reduced summer flow despite no decrease in rainfall. The Douglas-fir region is notable for high winter and spring precipitation and streamflow, and low summer rainfall and streamflow. Even within regions streamflow varies with topography and geologic conditions.

Streamflow also varies from year to year. Variations in the annual discharge by major forest regions are least in the Northeast and on the Pacific Coast; somewhat greater in the South, Midwest, and Rocky Mountains; and greatest in the Southwest (Busby 1963). In the southern Sierra Nevada in California, year-to-year variation in streamflow was least from high-elevation forest and alpine areas; streamflow from mid-elevation mixed-conifer forest was next in variation, and low elevation woodland and brush produced the most variable flow (Anderson 1963). Throughout northern California, the years of extreme low flow, the 10-year minimum flow, occurred progressively from high elevation to low, from

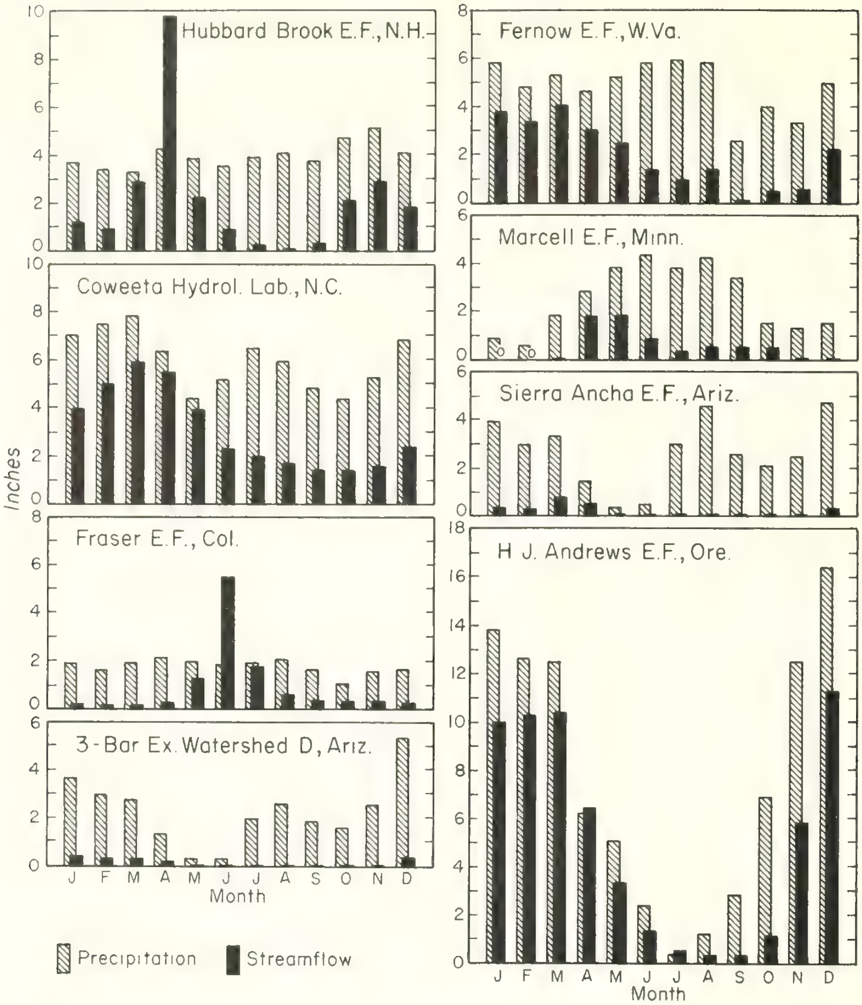

Figure 4—Mean annual precipitation and streamflow for selected experimental forests (E.F.) and other watersheds. Forest types are: Appalachian hardwoods at Fernow and Coweeta, northern hardwoods at Hubbard, bog-black spruce at Marcell, lodgepole pine and spruce-fir at Fraser, ponderosa pine and white fir at Siera Ancha, chaparral at 3-Bar, and Douglas-fir at Andrews.

northern latitudes to southern, from steep watersheds to less steep, and from watersheds with serpentine to watersheds with granite (Anderson 1975d).

Streamflow reflects local differences in physiography and climate. For example, in 137 watersheds in the Northeast, the average annual water yield among seven physiographic units ranged from 19 to 24 inches. Both annual and seasonal differences among regions were statistically significant at the 1-percent level, as were differences between clusters of watersheds within units (Lull and Sopper 1967). Yields can vary greatly within short distances. The same study recorded significant differences in annual and seasonal discharge within clusters of watersheds within a 30-mile radius. At the 4,700-acre Coweeta Hydrologic Laboratory in western North Carolina, average annual streamflow of small watersheds varies from 24 to 52 inches over an elevation difference of only 900 feet and a difference in average annual rainfall of 14 inches.

Within major forest regions some evidence shows that streamflow differs by forest type, particularly between hardwoods and conifers. In Michigan, water yield (as determined by groundwater measurements) from a 28-year-old jack pine plantation was 12.4 inches compared to 15.3 inches from 40-to 60-year-old deciduous stands nearby (Urie 1966). At Coweeta, streamflow from a mature white pine plantation, considering the difference in interception between pine and hardwoods, might be as much as 12 inches less than flow from the same site during an earlier

period when it was covered by a hardwood stand (Swank 1968). After fifteen years, annual streamflow was 7.9 inches less in the pine-covered watershed; the decrease occurred in each month but was greatest in the dormant and early growing seasons (Swank and Douglass 1974).

Among partly forested watersheds in the Northeast, those having a higher proportion of forest have more streamflow. This has been attributed not directly to the influence of the forest but to associated climatic, topographic, and edaphic conditions that usually increase flow (Lull and Sopper 1967).

Modifiers of the Forest Influence

The effects of hydrologic processes on streamflow are determined partly by scale—storm size, watershed size, and topographic differences; but the effect of these three factors on the forest influence is usually less important than physiographic controls.

Storm Size

The effect of the forest on streamflow is frequently stated as a percentage rather than an absolute amount. It should be apparent at this point that some forest influences are relatively more important for stormflow resulting from small storms: interception accounts for a larger proportion of small rainfalls, and soil-water storage opportunity of any given magnitude subtracts a greater proportion from the smaller rainfalls. Some forest processes thus have less effect, proportionately, on extreme events.

The situation may be different when rainfall augments snowmelt; then the forest's effect on large flows may be equal to or greater than that on smaller ones, especially on large and diverse watersheds.

One may well argue that the forest retains or detains some portion of any rainstorm, including the general and protracted storms described above, and thus somewhat reduces flood discharge and its peak. In a general sense this argument has merit: the forest does this. To some degree and in some places improved forest conditions do it better, provided that management accomplishes the needed forest improvement or that it reduces creation of additional poor forest conditions to the minimum.

Watershed Size

Many hydrologists reason that forests have greater influence on flood peaks from small watersheds than from large ones. Hoyt and Langbein (1955) explained it this way: "The larger the drainage area, the longer it takes flood waters to assemble in the lower reaches of the main stem. For this reason detention of infiltrated water for any given length of time has a lesser effect upon flood runoff as the size of the basin increases."

The situation is not always that simple. The effect forests have on flood peaks depends on the location of the forests and on the dominant processes of flood generation upon which they operate. The opportunity to prevent flood waters from collecting in the lower reaches by establishing or manipulating forest has been little appreciated, for American forests generally occupy the headwaters of rivers, a position favorable for delaying delivery of floodwater.

Physiography

Forest stormflow can differ according to physiographic region. For instance, for 137 watersheds in the Northeast, all of them 100 square miles or less in area and largely forested, the average annual number of daily discharges of more than 10 csm $ft^3/s/mi^2$ ranged from eight in northern New England to only one in the Coastal Plain (Lull and Sopper 1967).

Local stormflow can be related to elevation, which can indicate storage possibilities. At Coweeta, for example, forested primary ridges at 5,000 feet deliver almost 18 inches of direct runoff per year, whereas forest land at lower elevations delivers only 2.5 inches (Hewlett 1967b). Rainfalls of 8.4 to 10.8 inches in a December storm on three watersheds above 3,000 feet produced 5.0 to 8.8 inches of flow and maximum peaks of 68 to 167 csm. Rainfall on three watersheds below 3,000 feet was 6.8 to 7.0 inches; flow was 1.6 to 2.3 inches; and peaks were 22 to 32 csm (Hoover and Hursh 1944).

The classic stream morphological variables developed by R.E. Horton (1945) accounted for differences of 57 percent in flood peaks from large

storms on southern California watershed (Anderson and Trobitz 1949, Anderson 1950). Shape of watersheds influenced annual maximum daily flow, the 10-year flood, and the annual low flow, but not the average annual flow (Anderson 1975d).

Geology

Extreme differences in flood peaks were associated with differences in both topography and geology of watersheds in the northwestern United States (Anderson and Hobba 1959). North-sloping watersheds and those having unconsolidated sedimentary rock types produced smaller floods.

Dillon and Kirchner (1975) found greater differences in water chemical quality associated with different geologic rock types in watersheds rather than between land uses.

Both annual and low flows differed greatly on northern California watersheds located on nine different geologic types (Anderson 1975d). Some types (e.g., Cenozoic nonmarine) consistently had high values for all elements of streamflow. In contrast, granitic areas produced the least annual discharge and low flows but the highest 10-year flooding. Basalt had high annual discharge and low flows, but low 10-year floods. Serpentine areas had the greatest low flows, but other streamflow characteristics were low. Different geologic types produced differences in streamflow from as little as 30 percent of average to more than three times average for daily maximum as well as for average flows. Low flows were even more varied among geologic types; granitic rocks yielded low flows only 1 to 3 percent as high as those from the basic and ultrabasic rock type (Basalt and Serpentine).

Potter (1961) found it necessary to prepare separate predictions of peak flows for zones of loess and glacial till, sandstone and shale, limestone, and schist. White and Reich (1970) showed that floods are relatively low in limestone basins in Pennsylvania.

It has been well documented that forests, along or in combination with such structures as reservoirs and dikes, do not completely prevent the flooding of great valleys, but they play an important role. Forests augment reservoir storage with watershed storage by preventing debris from bulking flood flows, and by minimizing the loss of channel and impoundment capacity by sedimentation.

Forest and Frost

The occurrence of frost in the forest in winter in the more northerly latitudes has been thought to influence several hydrologic processes. Many foresters have believed that "concrete frost"—wet soil, solidly frozen—in the forest increases flood runoff. If concrete frost should form in the forest, it could prevent infiltration and cause overland flow. This may be concluded from evidence from nonforested areas. For instance, overland flow from concretely frozen soil on open fields was a principal source of runoff in the March 1936 flood near Ithaca, New York (Spaeth and Diebold 1938). Frozen soil was only in bare fields, not in neighboring woodland or grassland. Another study reported about 80 percent of 9 inches of rain and snowmelt ran off two potato fields that had a 14-percent slope. A neighboring forested area having 27 percent slope had less than 0.5 percent of overland flow (Bennett 1937).

Apparently, concrete frost occurs only sporadically in the forest. In the Adirondacks, under maximum snow accumulation, concrete frost about 2 inches deep was present at 30 to 40 percent of sampling points in sapling stands and at 15 percent of those in sawtimber. Frost usually occurred chiefly beneath conifer crowns in the snow-interception zone (Lull and Rushmore 1961). Konda (1955) reported sporadic frost to a depth of 18 cm under hardwoods in Japan. In a hardwood stand in New Hampshire, which had numerous mounds and depressions resulting from windthrow, Hart and others (1962) noted that through most of the winter snow insulated the soil and prevented frost formation. The few points where concrete frost was observed were on mounds. They concluded that any overland flow from a mound having concrete frost would be absorbed by the unfrozen slopes and depressions adjacent to it.

In New England and the Lake States, many other studies have also shown that the frequency of concrete frost in the forest is too low to have any real effect on overland flow (Hart 1963, Bay 1958 and 1960, Striffler 1959, and Wray 1959). Most of these studies also showed that concrete frost occurs more commonly under conifers than under hardwoods, and is most prevalent in open fields.

It seems obvious that soil freezing would have effects on watershed hydrology not simply explained by the concrete frost hypothesis; soil water is immobilized, even while migrating

upward to soil surfaces; a tremendous heat sink becomes established which must be dissipated, and certainly the pore space in the soil is temporarily reduced.

Thorud and Anderson's (1969) study of the forest floor as a heat sink during freezing revealed that bare soil froze 55 percent faster than litter-covered soil. A 2-inch layer of snow lengthened freezing time, but snow and dry pine litter together lengthened freezing time 54 percent over that required for the same thickness of litter alone, and 123 percent compared to snow alone. Water in the litter shortened freezing time as much as 61 percent. Therefore, we conclude that the forest floor and the soil beneath it comprise an important sink for energy, and that differences in forest floor conditions may cause significant differences in hyrologic processes.

Forestry, Erosion, and Water Quality

Probably the most current interest in hydrologic processes arises from their effects on water quality (Meier 1975). This section on hydrologic processes in relation to forestry must at least outline some of the individual water quality parameters that forestry can influence. The materials are the common particulates (inorganic and organic, living and dead), dissolved substances (inorganic and organic), amorphous substances, and gases. Radiant energy (transmitted, absorbed, and re-radiated) is also involved. These materials and influences are all reflected, somewhat inadequately, in such descriptors of water quality as turbidity, pollution, contamination, eutrophication, aeration, and water temperature. Since the hydrologic system is never in equilibrium, all measurements of its components present formidable sampling problems — and would do so even if we knew what to measure. We know how to measure erosion and its sedimentation products fairly well. We discuss erosion and its relation to water quality in detail because erosion is reported to cause 80 percent of the deterioration of water quality because products of erosion interact strongly with other components, and because erosion is directly affected by forest management.

Erosion and Sedimentation

The term "sedimentation," as used here, consists of three basic processes: erosion, sediment transport, and deposition. Erosion is the detachment and initial spatial displacement of soil, rock, or organic matter by whatever agent and in whatever state. Sediment transport is the movement of erosion products after initial displacement, and here includes movement of particles into the interstices of soil or rock. Deposition is the temporary or permanent halting of the movement of transported products of erosion.

Some characteristics of the forest system that affect erosion and sedimentation are unique among land types. These include the hydrologic properties of the soil mass, the types of terrain that the soil mass often occupies, the erosional processes and how they occur, and the high sensitivity of each process to change. Surface soil layers generally have high capacities for infiltration and percolation. Forest soils sometimes occupy slopes steeper than the natural angle of repose for the geologic material, for the soils are anchored by the tree roots. These steep slopes imply an erosional process of channel downcutting over long periods, and mass creep and occasional mass sliding from lower slopes into the channel (Anderson 1967a).

Surface erosion of forest sites usually follows intense rainstorms that follow baring of the soil by logging, fire, overgrazing, mass movement, or other causes. Landslides and mudflows may be started or accelerated by land use, but usually they too are associated with heavy rains and slide-prone conditions either in the soil mass or at the contact of the soil with the underlying rock. However, mass movements by soil creep and ocassionally by mudflows or landslides are pervasive natural processes that occur even in the undisturbed forest.

The three hydrologic processes principally initiating erosion and sedimentation are raindrop splash, overland flow, and streamflow scour. Interception may increase splash in those unsual situations where mineral soil has been exposed beneath the canopy by burning or trampling, for raindrops intercepted by a high canopy and dripping from it have greater mass and kinetic energy than ordinary rainfall (Tsukamoto 1966b) and therefore greater potential for causing splash erosion.

Infiltration capacity of forest soils is usually high. Surface erosion and transport of soil are eliminated when and where infiltration capacity equals or exceeds rainfall, snowmelt, and lateral overland flow additions. However, Ellison (1949)

showed how a bare, very permeable soil having a high infiltration capacity can be practically waterproofed by the splash erosion from 20 minutes of rainfall. But high infiltration capacities can have an undesirable effect. In some localities, high infiltration builds up soil water which locally destroys cohesion of the soil mass, augments soil creep into channels, or causes mass slope movement into them; or it may cause local soil saturation and growth of channels by solifluction (mudflows). However, a recent intensive study of slope stability in coastal Oregon (Harr and Yee 1975) showed that saturated soil was rarely found, and further that natural infiltrated and percolating water did not affect the soil aggregation that was essential to slope stability. Landslide processes are discussed under Timber Harvest—Landslides.

The surface of upland forests, where mineral soil is fully protected by a cover of litter and humus, contributes little or no sediment to streams. In these forests, erosion occurs almost entirely within the major and minor stream channels; local solifluction and creep move soil to the channel, and the cutting and transporting power of streamflow detaches particles from the banks and carries them downstream. The channel then is in dynamic equilibrium with the quantity and frequency of streamflow, which control the length, width, and carrying capacity of the channel. Hansen (1970) reported a 530 percent increase in the volume of suspended sediment in a 26-mile reach of a Michigan stream, largely as a result of channel bank erosion. When infrequent high flows occur, they overtax the channel and the flow starts to widen and lengthen it. Thus in any stream, sediment must be expected in times of extremely high flow. Extreme high flows may not only produce high yields of sediment, but may create unstable channel banks; so the watershed is more vulnerable to erosion for some time to come (Anderson 1970b, 1972).

Where areas of the forest floor have been disturbed by logging, grazing, or burning, infiltration is reduced by the compactive effect of moving equipment, trampling animals, or beating raindrops, and overland flow; soil erosion can result. Loss of soil then becomes a function of soil erodibility, length and steepness of slope, and the intensity of storm rainfall.

One index of the intensity of storm rainfall is the rainfall erosion index (the product of total storm energy in foot-tons per acre-inch and the maximum 30-minute intensity, divided by 100). This index differs widely from region to region. Average annual indexes from available data range from 75 to 200 for the Northeast, 200 to 600 for the Southeast, and 50 to 250 for the North Central States (Wischmeier and Smith 1965). In the West other indexes of erosion are more useful, such as volume and peak streamflow and the frequency of rainfalls versus snowstorms. These have been shown to be related to sediment production from forested watersheds, and hence to the erosion potential of forest sites (Anderson 1954, Wallis and Anderson 1965, Anderson 1975c).

After protective litter and humus have been removed, comparative soil erodibility controls erosion. Comparative erodibility has been studied particularly in California, Hawaii, and the Pacific Northwest (Anderson 1954, Anderson and Wallis 1965, Yamamoto and Anderson 1967). In California, for example, soil erodibility varied by a factor of eight among major soil types. Soils under Douglas-fir stands in eastern Washington were 45 percent more erodible than soils developed from similar parent materials in western Washington that had twice as much organic matter in the surface 19 inches (Balci 1968). In the southern Sierra Nevada, Willen (1965) found that granitic forest soils at elevations above 6,500 feet were potentially about 2.5 times more erodible than granite-derived soils below 4,500 feet. In northern California's forest-covered mountains, soils developed from acid igneous and schist rock types were more erodible than soils from the more basic and ultramafic types; and soils developed under fir were less erodible than those developed under ponderosa pine, brush, or grass (Wallis and Willen 1963). Similarly, soils in Hawaii that developed under the native ohia were more erodible than soils developed under introduced tree species (Yamamoto and Anderson 1967). Wooldridge (1964) reported that more than 40 percent of the soil erosion hazard in central Washington could be accounted for by variation in the content of organic-matter, pH, total porosity, and bulk density of the soil.

Stoniness of watershed soils may strongly affect erosion and water quality. Analysis of sediment data from watersheds in western Oregon indicated that streams in areas having gravelly soil became armored with coarse particles and hence had fewer days of turbid flow (Anderson 1975a). Results suggest, for example, that watersheds having 67 percent stone in their soil had only

about 23 percent as many days of turbid streamflow as soils containing only 17 percent stone.

Self-healing of disturbed areas can accompany the development of an erosion pavement (a layer of stones protecting the surface); however, this may be effective only after considerable damage has been done. Self-healing can be interrupted and erosion resumed by storms whose intensities exceed the infiltration capacities of the disturbed areas.

The dominant erosion processes differ considerably between watersheds, within management units, and over time. Mass movements, such as landslides, have accelerated erosion in areas considered to have recovered from logging (Fredriksen 1970). Within watersheds, unstable slope and soil combinations have been identified (Wallis 1963). The consequences of these differences in erosion potential on sediment yield and water quality are outlined under regional hydrologic characteristics affecting forestry and water. Interactions between sediment and other characteristics of water quality are discussed under each of those characteristics.

Although sediment is considered to be the most important single factor in limiting water quality, forest management also affects other factors that influence water quality.

Water Temperature

The forest influences the temperatures of soil water and streamwater by affecting the paths that water takes, by shading the ground and the stream, and by using energy for evaporative cooling. Management that changes any of these influences can change water temperature.

Raising water temperature may have both good and bad results; the balance depends on the particular stream situation. Warmer temperatures favor food production, which is all too small in many trout streams. If temperature of the stream is already near the upper threshold favorable for trout, opening the forest along the stream channel may be detrimental. The best trout fishing is in streams whose maximum temperatures never exceed 60 to 68° F. Water temperature for warm-water fish should not exceed 93° F at any time or place (Tarzwell 1960). Indirect effects of increased temperature include effects on dissolved oxygen. At elevated temperatures decomposition of organic debris in streams may deplete oxygen below critical levels for fish (Berry 1975).

Brown (1969) and Edinger and others (1968) have recently studied in considerable detail the microclimate of water surfaces and the heat balance in flowing streams. Brown reported wide differences in the amount of heat absorbed by flowing streams and stream bottoms. Bedrock bottoms absorbed as much as 25 percent of the energy, but gravel bottoms apparently were an insignificant energy sink. He reported differences of as much as 11° in May in temperatures of shaded and unshaded streams. Winter exposure of streams and their margins may be important to water storage. Walter T. Wilson, in a personal communication about 1947, attributed the temporary reductions of groundwater contributions to streamflow to freezing at stream margins. The formation of frazil ice in streams has also been related to the rate of cooling; here, too, the insulating effect of the forest may play a significant ameliorating role.

On the other hand, the biological productivity of streams that are too cold may be increased by raising stream temperature through much the same techniques as snowmelt is managed—cutting shade to the south while leaving trees on the northern stream margin to provide back radiation. Berry (1975) has modeled the effects of streamside clearing length on stream temperature. Biological productivity also can be affected by sediment in streamflow, for light penetration may be reduced so much as to inhibit growth of beneficial microorganisms.

Water Chemistry

Dissolved solids, most of which are essential nutrients in the forest ecosystem, are another element of water quality. In the mature forest the nutrient cycle generally approaches a steady state, and only small amounts of nutrients are discharged in the drainage water. As a result, volumes of dissolved solids are usually small in streamflow from forested areas and primarily reflect the geology of the area (Foggin and Forcier 1974, Dillon and Kirchner 1975).

The forest floor and forest soil have remarkable absorptivity. This was most notably demonstrated in a (1959-61) study at the Central Sierra Snow Laboratory of radioactivity associated with atomic bomb fallout. Radioactivity was measured in

incoming precipitation, in the snowpack, and in the snowmelt streamflow. In incoming precipitation, radioactivity reached as high as 50 times the water quality standard, and it was as high as 10 times the acceptable standard in the whole 10-foot-deep snowpack. Radioactivity in the streamflow from the snowmelt approached the standard of 1000 micromicrocuries per liter on only one day; usually it was on three-tenths of the standard or less. Public Health officials concluded that the forest floor and surface soil had absorbed most of the radioactivity. This may help to explain the ability of the forest to remove biological pollutants (Nikolaenko 1972, 1974) and chemicals that are applied in forest treatments.

Management practices affect the chemical quality of water by influencing the type of vegetation and rate of growth (thus affecting uptake), the amount and rate of deposition on the forest floor (as by production of logging slash or the removal of forest products), and the rate of decomposition of organic matter (by changing the exposure, temperature, and moisture content of the forest floor). Any treatment that changes the volume of streamflow may influence the removal of dissolved solids from the system in the drainage water, especially if surface soil, which is highest in such nutrients as nitrogen, erodes.

Of all pollutants dissolved in water, nitrogen deserves greatest attention in forest management (Tarrant 1972). In coastal Oregon, the total nitrogen in precipitation throughfall was nearly five times greater under the hardwood *Alnus* species than in rainfall not intercepted by forest canopy. Nitrogen was three times greater under conifers than in nonforested areas. The annual addition of nitrogen to the forest floor was as much as 100 lbs/acre (Tarrant and others 1969); so, for approximately 60 inches of precipitation, the concentration of nitrogen was about 7 p/m.

Natural addition of organic materials directly into the stream may temporarily degrade water quality. Slack and Feltz (1968) showed that water quality in a small stream was related to the autumn leaf-fall from reparian vegetation over the stream channel. Dissolved oxygen and pH decreased; water color, specific conductance, iron, magnesium, and the bicarbonate ion increased as the rate of leaf-fall increased. Stream quality improved rapidly after the channel was flushed by stormflow. Organic matter in the stream has benefits also, because it is a primary source in the chain of food production.

Forest practices that affect nutrients and other water quality characteristics are discussed later in the section Management for Water Quality.

Integrating Hydrologic Processes

How do we assemble the data on processes to predict water yield, floods, erosion, and sedimentation?

That depends on how each process relates to the objectives and on what technique is appropriate for predicting (Australian Academy of Science 1975). The two general classes of techniques, simulation and multivariate analysis, have somewhat different objectives. Use of both techniques has been greatly facilitated by developments in computer technology. Simulation as applied in hydrology is essentially a bookkeeping technique—individual hydrologic processes act sequentially on such an input as precipitation, and the summed results are routed to give an estimate of outputs varying with time. Notable working models include those by Crawford and Linsley (1964), Riley and others (1968), and Dawdy and others (1972). Many variations and extensions are constantly being reported. Essentially, the simulation technique relies on a satisfactory ability to evaluate the operation of hydrologic processes in space and time. The model can always be modified so that it will predict in a particular circumstance, but no greater insight into hydrologic processes seems to have come from the applications of simulation models.

Recent simulation models that deal with forest hydrology output include the Leaf and Alexander (1975) model, which integrates research results from Colorado into predicted outcomes of different cutting patterns. Galbraith (1975) has developed a method for predicting increase in water yield from timber harvesting for use in northern Rocky Mountain forests. In the Pacific Northwest, Ryan and others (1974) have reported development of an ecosystem model that includes forest hydrology outputs.

Other simulation models aim at evaluation of particular management practices, such as prescribed burning (Agee 1973), or timber harvest (Belter 1975), or water quality (Willis and others 1975), or particular outputs, as flood peaks (Dawdy and others 1972, Fogel and others 1974), or even particular processes as soil moisture (Zahner 1956). Each modeler has his own version of someone else's model, having made necessary

modifications to fit his own data available or own needs for predicting outcomes. Lombardo (1973) has concluded that there are no satisfactory models for water quality; the modeling by Willis and others (1975) seems to have promise in this difficult modeling development.

In contrast to simulation, multivariate analysis results have other uses in addition to prediction (Wallis and Anderson 1965, Lull and Anderson 1968). This type of analysis can determine the potential of unit areas of forests to produce particular water products (Anderson 1975d). It may relate a product to a cause having known frequency, and it can test the significance on a variable's effect on the product. Once the model is developed, independent variables may be manipulated to test the consequences of alternative possibilities in land management and to select the most desirable outcome.

The first applications were simple; many of them dealt with peak flows. Multiple correlations and regression were used to relate meteorological, topographic, and other watershed variables to peak discharges of storms, mean annual flood peaks, or peak flows of rare large storms. In 24 states where studies have been made, the principal hydrologic factors that are significantly correlated with the mean annual flood are drainage area, shape of basin, type of soil, and area of lakes (Benson 1962a). Annual peak discharges in New England were related principally to area of drainage, main-channel slope, and storage in lakes and ponds (Benson 1962b). Annual peak discharge of floods in Texas and New Mexico was related to drainage area, rainfall intensity, main-channel slope, storage, mean annual precipitation, and altitude (Benson 1963). In Northeastern watersheds, Lull and Sopper (1967) found that the highest mean daily discharges (at 0.1 percent flow durations) were related to precipitation intensity, slope, and percentage of area in swamps, but were not related to percentage of forest-covered area.

For small watersheds in most of the United States east of the 105th meridian, Potter (1961) related the maximum annual peak (equaled or exceeded on an average of once in 10 years) to drainage area, precipitation, topographic indexes, and drainage density. In an earlier study Potter (1953) had reported similar findings based on analysis of 51 watersheds in the Allegheny-Cumberland Plateau; he noted that the percentage of area in cropland, pasture, or woodland had no effect on the magnitude of the 10-year peak. He based this conclusion on his regression of peak flows versus area, for many of the largest deviations above the regression had 98 percent woodland, whereas those below had 50 to 60 percent cropland (hardly a conclusive technique).

On the other hand, Reich (1972) found that increased percentages of wooded area reduced flood magnitudes in Pennsylvania, at least those of 2.33-year return period; he concluded that the percentage of wooded area is a more important determinant that many geomorphic parameters of regional flood prediction equations. Peak discharges from watersheds in the Northwest have been related to several meteorologic, topographic, geologic, and forest-cover variables. The age and stocking of the forest below the snowmelt line during a storm were related to rain-snowmelt floods; snowmelt floods were related to the area of poorly stocked and burned forest (Anderson and Hobba 1959).

We conclude the discussion of classical hydrologic processes, their modifiers, and some of their applications realizing that, in almost all forest situations, the spatial distribution of many of these processes may differ greatly from these classic models. For example, water moving downslope in both saturated and unsaturated flow is effective in extending the period when water is available for transpiration to the forests on lower slopes, adjacent to channels, and at locations with shallow or impervious strata (Tsukamoto 1966a). Almost all experimental measurements of water use from watersheds have indicated greater use than would have been predicted from measurements of soil-water depletion and interception.

Martinec (1975) reported from a study of tritium content of subsurface flow that outflow from the watershed represented water hitherto in subsurface storage for "a number of years." Infiltrated water on the watershed was substituted for, perhaps by some pressure wave phenomena, (Vischer 1970 quoted by Martinec 1975).

Forests through their effect on the distribution of falling rain, on distribution of snow, on freezing of the soil, and on the production of ice lenses within snowpacks, create situations of highly varied water percolation, typically under conditions quite difficult to measure quantitatively. It will become evident that these spatial and time variations of soil moisture have implications not only for management for water yield from forest but also for control of flood flows and sedimentation.

II - FOREST TREATMENT AND WATER

The hydrologic response—water yield, floods, and water quality—to forest treatment depends on the characteristics of the forest, the nature of the treatment, and the posttreatment recovery of those watershed attributes that affect the hydrology. The forest itself may be characterized by such attributes as type, age, and density, or by more fundamental measures such as basal area or biomass, or measures that attempt to characterize the whole forest ecosystem. The treatments themselves vary widely, from harvesting, prescribed burning, grazing, and planting, to the havoc wrought by insects, diseases, winds and wildfires. The extent to which the forest's influence is altered depends on the intensity of treatment or assault. The greatest effects are usually produced by clearcutting, intense burning, heavy grazing, intensive planting, catastrophic attacks by insects and diseases, and blowdown. The size of the area—and the proportion of the watershed—subjected to the treatment or assault often have primary importance.

Some effects are influenced too by climate, soils, topography, and geology. They differ by season of the year, and are influenced not only by a specific forest happening but also by what occurred before and after it: how long recovery takes, the nature of replacement vegetation, and so forth. Thus the subject is complex. Presentation here is in terms of qualitative effects on hydrologic processes illustrated by some quantitative examples.

Timber Harvesting

Timber harvesting includes severing trees from their stump, cutting the bole into sections, and removing the timber from the watershed. Construction and use of skidtrails and logging roads is usually an integral part of the harvesting operation, which may also include burning or other disposal of the slash. The impact of timber harvesting on the water resource depends upon the severity of the changes in vegetal cover, the exposure and compaction of the mineral soil, and the proportion of watershed affected (Megahan 1972, Stone 1973). It is also influenced by the rate at which soil and vegetation recover, either by natural reproduction or by the planting of woody and herbaceous species. Timber harvesting affects the water resource by its influence on the fundamental hydrologic processes.

Interception

Interception of precipitation by deciduous hardwoods is not greatly reduced by forest cutting; logging residue (stumps, branches, and foliage) and the remaining understory continue to intercept moisture. If the area is to remain in the forest cover, revegetation within 10 years can restore much of the interception. Partial cutting in hardwoods has little effect on snow interception. In northern Minnesota, for example, maximum snow accumulations in four aspen stands thinned to 50, 65, 80, and 115 square feet of basal area were 4.5, 4.1, 4.2, and 4.3 inches of water respectively (Weitzman and Bay 1959).

On the other hand, interception by conifers may amount to as much as 30 percent of annual precipitation; therefore, interception by conifers may be reduced more by forest cutting than it is in hardwoods. Such reduction can substantially increase streamflow. Regeneration of conifers is not initially as rapid as the resprouting of hardwoods. It may take 20 to 40 years in the East and 50 years or more in parts of the West for a cutover stand to even approach full interception.

Snow Accumulation

Snow accumulation is markedly affected by timber harvesting; increases in the maximum snow accumulation in four western states after heavy cutting ranged from 22 to 40 percent (*table 6*). Light cuttings increased snow accumulation by 10 to 17 percent. In Minnesota, percentage increases were much larger because snow accumulations were small. The greatest absolute increases, up to 19 inches in terms of water equivalent, have been in the deep snowpacks of the central Sierra Nevada of California, where both interception and winter snowmelt were involved.

Often excess snow in openings is a redistribution of snow, and it is partly balanced by a decrease under the trees (Hoover and Leaf 1967, Hoover 1971, 1973). Anderson and Gleason (1959) reported that one-half of the 13 inches (water equivalent) of greater amount of snow found in a cut strip was in effect "stolen" from the forest to

Table 6–*Increase in maximum snow accumulation (water content) after cutting in western conifer forest*

Location and forest cover	Treatment	Maximum increase in snow accumulation	
		Inches	*Percent*
(1) Fraser Exp. Forest, Colo.	Uncut: 11,900 fbm	0.0	
Mature lodgepole pine	Cut (residual volume):		
	6,000 fbm	.81	12
	4,000	1.01	15
	2,000	1.49	21
	0	1.99	29
Young lodgepole pine	Heavy thinning (reduction from 4,400 to 630 trees per acre)	2.3	23
	Light thinning (reduction from 4,400 to 2,000 trees per acre)	1.7	17
Mature Englemann spruce-subalpine fir	Removal of 60% of volume by strip cutting and group and single-tree selection	2.8	22
(2) Front Range, Rocky Mountains, Colo. Ponderosa pine and Douglas-fir	Selection cut	.45	6
	Commercial clearcut	1.21	29
(3) North Central Wyo. Lodgepole pine	Clearcut blocks	2.5	40
(4) Willamette Pass, Oreg. Mountain hemlock and true fir	Strip-cut, strips 2 chains wide	5	15
(5) Central Sierra Snow Laboratory, Calif. (NE) Red fir	Clearcut	11	23
	East-west strip, 1 tree-height wide	12	26
	Block cutting, 1 tree-height wide	15	34
	Selective cutting; crown cover reduced from		
	90% to 50%	2	5
	90% to 35%	9	19
	Commercial selection cut	7	14
	Wall-and-step forest	19	25
(6) Minnesota Black spruce	Single-tree selection	.1	4
	Shelterwood	.7	28
	Clearcut strip	1.5	60
	Clearcut patch	2.0	80

Compiled as follows: (1) Wilm and Dunford 1948, Love and Goodell 1960; (2) Berndt 1961; (3) Berndt (1965; (4) Rothacher (1965b; (5) Anderson 1956, 1963, Anderson and others 1958, Anderson and Gleason 1960; (6) Weitzman and Bay 1959.

the leeward. On the other hand, the study of snow in 36 natural openings showed greater amounts in both forest openings and the forest adjacent to openings than in the continuous forest (Anderson and West 1966, Anderson 1967b). Snow in openings melts more rapidly than snow within the forest, and this can increase or decrease peak flow, depending on synchronization with melt elsewhere on a watershed.

Haupt (1973) reported the role of snow accumulation in relation to wind and surface exposure near major ridges, and suggested

cutting forest on the windward side to store snow to the lee.

Surface Detention

Logging, land clearing, or fire may reduce roughness of ground or stream channel and thereby increase the speed of flow in saturated areas and in channels. Timber harvesting that augments accumulation of snow may increase detention capacity in the snowpack. Detained water may have contradictory effects when the snow melts, depending on the timing and the location of the snowpack in which the additional water was detained. Forests at high elevations, cut or uncut, may have sufficient detention capacities for rain and slow snowmelt in early season. At intermediate elevations, forest cutting usually allows the rapid ripening of snowpacks, especially on south slopes. Detention storage capacity during rain on snow is lost and melt is speeded (Anderson and Hobba 1959); exposure of snow surfaces in openings may speed melting by increasing latent heat exchange from the moist atmosphere to the snow (Anderson 1969). At lower elevations, the speeding of snowmelt by forest removal may help to desynchronize peak flows from different parts of the watershed (Satterlund and Eschner 1965).

Other than surface detention in snowpacks, timber harvesting may cause small difference in detention on the soil surface, as in pondage in skidtrails, behind road fills, and in stump depressions resulting from whole-tree logging. Most of these effects have not been separately evaluated.

Infiltration, Overland Flow, Erosion, and Sedimentation

These four processes are discussed together because when infiltration capacity is sufficiently reduced, overland flow and erosion usually follow. Erosion of soil provides material for sediment in the stream, although not all the eroded material reaches the stream and some of the sediment comes from the channel area rather than from the land surface.

Merely cutting trees does not affect infiltration capacities. The generally high rates of infiltration characteristic of the forest remain after harvesting except where logging activity has exposed the mineral soil or caused soil compaction. The influence of the organic layers and the forest soil structure persists for some years after cutting; when regrowth is reasonably prompt, new organic contributions are provided to maintain soil stability, which prevents degradation.

Clearcutting mature hardwoods at Coweeta (Hoover 1945) produce no overland flow and consequently no erosion. Cut trees were left where they fell, and a heavy ground cover rapidly developed. At the Hubbard Brook Experimental Forest, felling the trees and treating with herbicide to eliminate ground cover (a treatment for research purposes only), increased sedimentation fourfold during the next 2 years, from 8.6 to 34 tons per square mile per year (Pierce and others 1970). Apparently there was no overland flow, and the additional sediment came from the stream channel.

Harvesting reduces infiltration capacity to the extent that forest soil is exposed and compacted by roadbuilding, skidding, and hauling. Careful logging may disturb no more than 10 percent of the area; overland flow resulting from reduced infiltration may then be of little consequence. In contrast, careless logging can compact and disturb as much as 40 percent of an area, reducing infiltration from several inches per hour to a fraction of an inch, and generating damaging overland flows from high-intensity rainfalls. Murai (1975) reported that infiltration in a cutover forest that was heavily disturbed was about 1 inch per hour—only 20 percent of that in the uncut forest.

In some situations, erosion is relatively easy to control. Logging on coarse-textured, permeable soils in the front range of the Rockies, with careful roadbuilding, has produced little sediment (Leaf 1966). The essential stability, despite heavy cutting, of the glaciated soils of New England's forested mountains also has long been recognized (Cleland 1910).

Elsewhere the situation can be quite different. On clay soils at Coweeta, roads and logging produced maximum sediment concentration in streams of 7,000 p/m as compared to 80 p/m for an undisturbed area. Turbidity from the logged area averaged 93 p/m compared with the 4 p/m from the check area. Repeated measurements of road cross sections showed that in 4 years the 2.3 miles of road lost 6,850 cubic yards of soil (Hoover 1952). This impaired water quality of the stream

that drains an 1,880-acre watershed so severely that the timber value was judged to be less than the cost of treating the water (Hursh 1951).

Surveys of eight major basins in southeastern states reported that logging activities were responsible for more than half of the increases in sediment production from forest lands in seven of the basins (Dissmeyer 1976).

In Arizona, logging and road construction increased sediment yield from a 248-acre watershed from 3.5 tons annually to 21 tons from only two summer storms and 57 tons from two winter storms (Rich and others 1961). Before logging, a certain 2,500-acre watershed in the Sierra Nevada yielded 0.4 ton of sediment per acre per year. The first year after a commerical selection cut of one-fourth of this watershed, the logged area yielded 6.1 tons per acre; in the following year it yielded only 1.8 tons (Anderson 1963). Increases in concentrations of sediment were associated mostly with the high discharge classes: the highest 12 percent of the streamflow carried 60 percent of the sediment. Sedimentation rates dropped rapidly after logging. For a high discharge class of 55 to 79 ft^3/s, the rate before logging was 20 p/m; during the first, second, and third years after logging, the rates averaged 190, 90, and 45 p/m (Anderson and Richards 1961).

Logging roads—Logging roads and their unprotected cuts and fills are a primary source of sediment from forested watersheds. Movement of sediment downslope from a road depends on the amount and velocity of runoff, the availability of erodible soil, and the obstructions to sediment transport (Haupt 1959). Road cuts can produce tremendous quantities of sediment, depending upon their slope and aspect.

In south central Idaho, three adjacent watersheds with highly erodible granite-derived soils produced sediment yields of 12,400, 8,900, and 89 tons per square mile in one season following construction of logging roads. Watersheds without roads yielded no measured sediment (Copeland 1965).

A similar relationship was found in the analysis of 29 watersheds in western Oregon: an increase in the annual timber cut from 0.6 to 1.5 percent would increase sediment loads an expected 18 percent; increasing total road area from 0.1 to 0.55 percent would increase sediment loads 260 percent (Anderson 1954).

In central Idaho, during a six-year study, the effects of skyline logging with no roadbuilding were compared with those of jammer logging. (The jammer has an A-frame with winch and cable mounted on a truck; it requires closely spaced roads.) Skyline logging with no roads increased sediment deposition by only 1.6 times; in contrast, jammer-logging with numerous roads, which may disturb 25 percent of an area, increased deposition by 850 times for the 6 years after road construction (Megahan and Kidd 1972, Megahan 1975).

Gradual reduction of road-induced sedimentation has been observed on some watersheds; however, Megahan (1975) believes that full recovery in central Idaho may not be expected. A watershed crossed by a 37-year-old road, apparently fully stabilized, still produced twice as much sediment as similar but unroaded watersheds. Historically, roads often have been upgraded from dirt to surfaced roads, typically with major realignment; such upgrading may be beneficial in midslope locations, but highly detrimental in increasing sedimentation from streamside roads (Anderson 1974). Roads in steep watersheds show twice as much increase in sedimentation as roads in moderately sloping watersheds (Anderson 1976).

In the Douglas-fir region, only one-third of the area of a typical road is occupied by the roadbed; cut and fill slopes cover the remainder of road area (Dunford 1962). Forest roads in the Intermountain region have about 8 acres of cuts, fills, and ditches for every mile of road (Usher 1961). In Mississippi, sawtimber harvesting disturbed 15 percent of logged areas; 5 percent was contributed by roads, 7 percent by skidtrails, 2 percent by log movement, and 1 percent by landings (Dickerson 1968).

Under some conditions, sediment production from logging roads can be both substantial and prolonged. After 1.7 miles of road were built on 6.2 percent of a 250-acre watershed at the H.J. Andrews Experimental Forest, the first storm of the rainy season produced a turbidity (suspended sediment concentration) of 1,780 p/m, 250 times the concentration in the undisturbed watershed. Sediment concentrations remained high during the first 2 months of the rainy season, and during the next 2 years they continued at about twice the concentration measured before road construction (Fredriksen 1965b).

The degree of disturbance and consequent erosion and sedimentation differ widely according to the erodibility of soil, the intensity of the timber cut, the care used in logging, and the type of equipment used.

There is considerable evidence that careful logging minimizes sediment production. Successful erosion prevention or control depends on the care and skill used in skidding and hauling the timber products and in the construction and maintenance of trails and roads used for these purposes. Failure to close substandard roads after logging—leaving them for recreational or other use—can indefinitely prolong erosion and production of sediment.

Less soil is lost from high-quality roads than from less well built roads. At Fernow Experimental Forest, sediment production per unit length for a good road (of moderate slope and with drainage provided) was only about half that for a poor road (with no restriction on grade and no drainage provided) (Weitzman and Trimble 1952). The greater the use of skidroads, the greater the soil loss. Heavily used skidroads at the Fernow lost 3.7 inches of soil during skidding; lightly used roads lost only 1.0 inch (Trimble and Weitzman 1953). Of course, both of these rates would produce high turbidity if the lost soil reached a stream.

The density and grade of roads may be significantly reduced by adequate planning. Logger's-choice road system (unplanned) at the Fernow Experimental Forest occupied 4.8 to 7.0 percent of the area and had grades of 14 to 24 percent; a planned system occupied 2.5 to 4.6 percent and had grades of only 9 to 15 percent. Careful planning reduced the area in skidroads by 40 percent and eliminated steep grades (Mitchell and Trimble 1959).

Care in constructing road drainage is needed in areas where slopes are unstable; Harr and Yee (1975) suggest that drainage from culverts can destroy soil aggregation necessary for natural stability of slopes.

Another study at the Fernow showed that amounts of erosion and sedimentation resulting from logging 50-year-old hardwood stands were closely related to the severity of soil disturbance, which in turn depended principally on the care used in laying out and draining skidroads. Logging 86 percent of the timber volume with no road plan and no provisions for drainage resulted in a maximum turbidity of 56,000 p/m; 38 percent of all samples had more than 10 p/m. Logging 20 percent of the timber volume using careful road planning and provision for adequate drainage produced a maximum of 25 p/m, and only 1 percent of all samples had more than 10 p/m. Meanwhile, the unlogged control watershed showed a maximum of 15 p/m, but almost all samples registered less than 10 p/m (Reinhart and others 1963).

This study emphasized how quickly sedimentation diminished after logging. Streamflow from the most heavily eroded watershed averaged turbidity of 490 p/m during logging; within the first year after logging this dropped to 38 p/m, and in the second year to a negligible amount (Reinhart and others 1963).

A later clearcutting operation on the Fernow (Hornbeck 1967), for which skidroads were carefully laid out, drained, and maintained, yielded streamflow with a maximum turbidity of 83 p/m, with 95 percent of the samples (taken periodically) having turbidities between 0 and 10 p/m. This study demonstrated again that, with care, these forested watersheds can be clearcut and the products removed without seriously increasing stream turbidity. Hoover (1952) pointed out that ordinary logging procedure at Coweeta produced more sediment: an average turbidity of 93 p/m compared with 4 p/m from an unlogged watershed; maximum turbidities were 7,000 and 80 p/m, respectively.

On an 800-acre timber sale on the Chattahoochee National Forest in Georgia, careful logging produced an average suspended sediment content of 5 p/m as compared to 4 p/m from an unlogged watershed (Black and Clark 1958).

Vogenburger and Curry (1959) reported that during 10 years of logging on the Waynesboro, North Carolina, 8,000-acre watershed, 50 miles of road were built and 13 million board feet of timber were harvested—all without damaging the water resource. Sediment yields from a carefully logged watershed on the Fraser Experimental Forest in Colorado increased to about 100 tons per square mile the first year after logging; annual yields in the next 8 years ranged from 65 tons to negligible accumulations. However, over an 8-year period, starting with the year of logging, a statistical comparison showed no difference in mean annual sediment yields between the logged watershed and two nearby undisturbed watersheds even though timber harvesting increased streamflow by 25 percent (Leaf 1966). In California, good logging

showed no detectable increases in sediment discharge, independent of effects of road building and increased streamflow; for similar watersheds poor logging showed increases in sediment discharge of about 19 percent for each percent of watershed area so logged (Wallis and Anderson 1965). Sediment discharge increased also with increased total streamflow brought about by such activities as road clearing or logging. In northern Idaho, Snyder and others (1975) reported that clearcut logged and slash burned areas produced increases in filterable solids of 4 to 14 times that from unlogged areas. A moratorium on logging and road construction and a watershed rehabilitation program in the upper half of the South Fork of the Salmon River in Idaho since 1965 has been associated with a decrease in fines in the downstream river channel (Platts and Megahan 1975).

The area disturbed by logging with several types of equipment has been studied *(table 7)*. Since these studies were not conducted and reported uniformly, strict comparisons cannot be made. They do show, however, that tractor logging disturbed (either quite severely or of a severity not designated) from 3 to 31 percent of the area; the various types of cable logging caused similar disturbance on only 2 to 16 percent of the area. Megahan and Kidd (1972) reported that in Idaho substitution of skyline logging for the jammer could reduce disturbance by road construction by 75 percent. In the Pacific Northwest, skyline crane logging requires only about one-third the roads necessary for high-lead logging (Binkley 1965).

Skyline crane logging disturbs soil even less than high-lead logging (Dyrness 1967b, Ruth 1967). The skyline crane yards logs from steep slopes with minimum road construction. Its pattern of soil disturbance is less conducive to erosion because its skidtrails are mostly across rather than up and down the slopes. The disturbance it creates is shallower and more evenly distributed than that created by the high-lead system (Ruth 1967).

Balloon logging disturbs soil even less than skyline crane logging (Dyrness, cited by Rice and others 1972), but logging by helicopter disturbs soil the least of all (Binkley, cited by Rice and others 1972).

Landslides—Road construction and tree cutting sometimes trigger landslides. Thirty-four of 47 mass soil movements during the winter of 1964-65 at the H. J. Andrews Experimental Forest in Oregon were found along roads, although only 1.8 percent of the total area of the forest was in road rights-of-way. Movements were attributed to backslope, fill, or drainage failure. Along the 1.7 miles of road, there were 34 individual mass movements, totalling 185,000 cubic yards of earth (Dyrness 1967a). Wide differences in slide frequency were associated with geologic rock types in the area (Swanson and Dyrness 1975).

Croft and Adams (1950) attributed landslides in the Wasatch Mountains of Utah to loss of mechanical support from root systems cut and burned, and to some extent damaged by excessive livestock grazing. In southeastern Alaska near Ketchikan, the number and acreage of slides increased 4½ or more times after logging began in 1953 (11 slides during the 100 or more years before logging, 68 slides in 9 years during and after logging). Most slides occurred after 1959; the 6-year lag perhaps reflected the time required for root decay. Road construction caused slope failure at several locations (Bishop and Stevens 1964). Nakano (1971) discussed resistance to uprooting as an index of landslide control. He observed that planted trees become more effective as they get older, but that the effectiveness of roots of tree stumps declines with passing time. Trees reach half-effectiveness at about age 30 years; stumps decline to half-effectiveness in 8 years after logging.

Soil and rock movement and sedimentation during a slide may be spectacular. Fredriksen (1963) described one at the H. J. Andrews Experimental Forest, apparently triggered by rain, snowmelt, a road, and a culvert. This slide carried streambed gravels equivalent to 10 cubic feet (about 0.5 ton) per acre and suspended sediment equivalent to 1.1 tons per acre through the channel. Three years later a much heavier rain-on-snow storm deposited about 3,000 cubic feet per acre of gravel, rock, and logs in the stream channel—300 times the amount measured in the 1961 slides.

In the interim, almost one-third of this watershed had been logged by a high-lead system and then the slash was burned. One of two adjacent areas on this watershed was an uncut control. On the other one, 75 percent of the timber had been harvested by a skyline crane (Fredriksen 1965a). During the 1960-68 period the area logged by high-lead (6 percent was covered by roads) and then burned produced 109 times as much sediment discharge as the uncut control, and the area harvested by skyline crane produced only 3.3 times as much sediment as the control (Fredriksen 1970). Slope failures were involved in this sedi-

Table 7–*Area disturbed by logging, for various locations, types of cutting, and equipment*

Location and forest type	Cutting	Equipment and percent of logged area affected
(1) New York and Quebec Spruce	Commercial clearcutting	Skyline crane: skidtrails scattered and not continuous; no water concentration
(2) West Virginia: Appalachian hardwoods	All types	Tractor: Planned skidroads 2.5 to 4.6 Unplanned skidroads 4.8 to 7.0
(3) Illinois: Hardwoods	Selective cutting, about 50% volume	Tractor: Log lengths 31 Tree lengths 18
(4) Mississippi: Southern pine	All types, for saw-logs and pulpwood	*Litter* / *Bare soil* Wheeled tractor 4 / 13 Crawler tractor 6 / 8 Mule team 6 / 6 A-frame, cable 4 / 8
(5) Idaho: Ponderosa pine	About ¼ to ½ volume: single-tree and group selection	Tractor: Single tree 3 to 18 Group 3 to 13
(6) Washington: Douglas-fir	Clearcutting	Tractor: 26 in skidroads
(7) Washington: Ponderosa pine Douglas-fir	 65% volume 81% volume	*Deep soil* / *Shallow soil* Tractor 15.9 / 6.3 Skyline crane 3.2 / 2.2
(8) Eastern Oregon and Washington: Ponderosa pine	Crown density reductions of 48% to 67%	Tractor: 22 (bare)
(9) Eastern Oregon and Washington: Ponderosa pine	54% of board foot volume	*Deep soil* / *Shallow soil* Tractor 15.0 / 5.9 Cable 1.9 / 13.3 Horse 2.3 / 9.5
(10) Oregon Douglas-fir, western hemlock	Clearcutting	*Disturbed* / *Compacted* Tractor 62 / 27 High-lead 40 / 9
(11) Oregon: Sitka spruce, western hemlock	Clearcutting	High-lead: 16 (bare) Skyline crane: 6 (bare)
(12) Oregon: Douglas-fir, western hemlock	Clearcutting	High-lead: 14.8 (bare) Skyline crane: 12.1 (bare)
(13) California: Sugar and ponderosa pines, white fir	40% to 90% volume	Tractor: 22 (bare)

Compiled as follows:
(1) Fobes 1950
(2) Mitchell and Trimble 1959
(3) Herrick and Deitschman 1956
(4) Dickerson 1968
(6) Steinbrenner and Gessel 1955
(7) Wooldridge 1960
(8) Garrison and Rummell 1950; 1951
(9) Garrison and Rummell 1950; 1951
(10) Dyrness 1963'
(11) Ruth 1967
(12) Dyrness 1967b
(13) Fowells and Schubert 1951

mentation. The first slide originated from soil spilled over the hillside below a road being constructed. Thirty-two other landslides occurred in the patch-cut watershed during the storm in December 1964; all but three were adjacent to stream channels. No landslides occurred in the uncut control watershed.

Landslides are not so serious a problem in much of the East as in parts of the West. Flaccus (1958) concluded that the slides he studied in New Hampshire were not appreciably affected by logging or road construction.

A Logging-Flood-Sediment Interaction—Predicting expected increases in sedimentation after logging may be complicated by weather variations. Studies have shown that watersheds may produce much more sediment in years immediately following a major flood especially when the areal extent of major storms coincides with watershed areas harvested by improper logging methods, or by inadequately designed roads (Anderson 1970b). For example, the first year after the December 1964 flood in north coastal watersheds of California, sediment production increased by as much as 33 tons per acre. Sedimentation the first year *after* this flood was as much as five times the preflood amount. Analysis of records from 31 watersheds after such major floods showed that the sediment increases were associated with topographic differences, the size of the flood in the individual watersheds, and the past land use in watersheds; these differences also affected the time to recovery from the major flood effects on sedimentation.

The major result of that study (Anderson 1970b) was the evidence that poor logging practices, such as locating roads adjacent to streams and landings in draws, caused increased sediment concentration *after* the floods. Contrasting two watersheds, one with the average amount of poor logging (19.2 acres per square mile or 3 percent of the total area) and the other with no logging, the watershed with the combination of poor logging and a large flood had a 70-percent greater increase in sediment after the flood. The increases in sediment discharge were greatest on the steepest watersheds and on those at higher elevations. Increases in sediment discharge lessened each successive year after the flood; however, the return to normal conditions can be slow.

There is no question that poor logging increases sedimentation by several times the normal. The rate of watershed recovery after a combination of poor logging and major floods was analyzed by the regression of annual sediment yields of some northern California watersheds. This analysis indicated that 10 additional years would be required for recovery of a watershed subjected to poor logging over 100 percent of its area and to the impact of the 1964 flood (Anderson 1972).

Evapotranspiration

Evapotranspiration may be reduced in proportion to the area of the timber stand which is cut. The reduction integrates reduced interception, reduced transpiration from the canopy, and a small increase in evaporation from the more exposed forest floor. The reduction occurs principally during the growing season. Clearcutting may also increase snow evaporation—in California, for instance, from about 0.6 to 2.6 inches, depending on exposure (West 1962).

Evapotranspiration is rarely measured directly. Aerodynamic or mass and energy budget techniques have not been widely used in evaluating forest harvest effects on evapotranspiration, chiefly because of the sampling problems involved. Our information on how timber harvesting influences it is gained mostly from the measurement of changes in soil-water storage and streamflow.

Soil-Water Storage

Both storage capacity, at least to a slight extent, and storage opportunity can be reduced by cutting trees. Capacity is reduced proportionately as soil organic matter and accumulations of forest humus are reduced. Where regrowth is rapid, as noted, this can be only a minor effect. Storage capacity and opportunity are also reduced where the forest floor is transformed to roadbed or skidtrail; usually this is only a small percentage of the harvested area.

However, in the whole logged area, the opportunity for storage may be greatly reduced during the growing season and for some time after it. For example, Ziemer (1964) found that in early September, when moisture depletion is maximum in red fir on the western slopes of the Sierra Nevada, forest openings 1 year old had 6.9 inches less storage opportunity per 4 feet of soil than the surrounding forest. With regrowth the difference rapidly diminished: 2.9 inches at 5 years, 1.2 inches at 10 years, and negligible differences at

16 years. Reduction of storage opportunity, of course, is water "available for streamflow" in the succeeding year (Wilm and Dunford 1948).

Shallow soils undergo little change in soil-water storage opportunity, because regrowth or a replacement ground cover dries the soil readily, using about as much water as the original forest cover did.

Duration of the effect of clearcutting is related to soil depth. Seven years after commercial clearcutting of a shallow-soil watershed at the Fernow Experimental Forest, 78 percent of the original increase in streamflow had disappeared. On a watershed at Coweeta with a much deeper soil, 20 years was required to achieve a similar reduction after clearcutting (Lull and Reinhart 1967).

In snow regimes, the duration of reductions of evapotranspiration following timber harvest depends on the aerodynamic placement of snow in relation to the opportunity for soil moisture storage (Anderson 1970a, Hoover 1973).

In upland forests, three measurements may enable estimation of actual evapotranspiration and indicate the possiblity of increasing streamflow by forest cutting: soil-water measurements at the beginning of the growing season when the soil is wet and at the end of the season when it is dry, plus a record of summer rainfall. (In areas where overland flow occurs or where the soil may be fully recharged by summer rains, estimating is more complicated.) In Utah, for instance, measurements of summer losses of soil water showed that mature aspen stands used 0.5 to 4.5 inches more water from the upper 6 feet of soil than first-year sprouts of cut aspens (Tew 1967). These differences diminished rapidly in succeeding years as sprout stands matured. Mature Gambel oak utilized 1/4 to 1 inch more soil moisture than 1-year-old sprouts. (Tew 1969). Clearcutting oak and aspen can prolong savings only if subsequent sprouting is prevented. Interclonal root connections also may reduce the effectiveness of small cleared areas of aspen (Tew and others 1969). Clearcutting of lodgepole pine in the Uinta Mountains of Utah resulted in 4 inches more water left in the soil at the end of summer as compared with uncut stands (Johnston 1975).

In California, fall soil-water deficits ranging from 3 to 17 inches on natural forest sites may be reduced to 1 to 8½ inches after logging or brush removal (Anderson 1969).

Soil-water and supplemental measurements in a red fir forest in California suggest water losses of 24 inches on unlogged forest, and first-year losses of 12, 15, and 18 inches for strip, block, and selection cuts, respectively, or savings of 12, 9, and 6 inches (Anderson 1969).

Thinning can reduce use of soil water by 1 to 3 inches. In Oregon, thinned stands of ponderosa pine saplings used 1 to 2 inches less water during the growing season than untreated stands (Barrett and Youngberg 1965). Helvey (1975) found that heavy thinning of 70-year old ponderosa pine in central Oregon reduced summer soil moisture depletion by from 2.4 to 4.5 inches, but only during the first three years after treatment.

In the fall of three successive years, a Minnesota red pine stand, thinned to 60 square feet of basal area, had 1.8, 0.5, and 3.2 inches more soil water than an unthinned stand with 140 square feet (Bay and Boelter 1963). These studies indicate that forests use less soil water after cutting than before, so more water is available for streamflow. However, these are index values only. Hydrologic processes are too complicated to permit translation of differences in soil moisture and other separate processes directly into increases in streamflow.

Quantity of Streamflow

Increases in streamflow after various intensities of cutting have been demonstrated in many parts of the country (*table 8*). Treatments other than timber cutting are also shown in the table for comparison. Considering first-year increases only, the heavier the cut, the greater the increase in flow. Thus, maximum first-year increases in streamflow following clearcutting, partial clearcutting, and selection cutting are about 18, 8, and 4 inches, respectively. Where average annual precipitation is 48 to 90 inches, first-year increases following clearcutting ranged from 5 to 18 inches; with 21 to 28 inches precipitation, increases were 1 to 3 inches; where precipitation was 19 inches, no increase was reported.

In Arizona removing mixed conifer forest vegetation has increased water yields approximately in proportion to the percent of the area in cleared openings and in proportion to the amount of precipitation during a year (Rich and Thompson 1974). "Removal of moist-site forest vegetation—Douglas-fir and white fir—from 80 acres of a 248-acre watershed increased water yields 45 percent. Clearing an additional 100 acres of dry-site forest vegetation—dominantly ponderosa pine—further increased water yields. Compared to original conditions, increases varied from 81 percent at 1-inch yield from the control watershed

to 109 percent at 7-inch yield from the control. Clearcutting 83 percent of a 318-acre watershed resulted in water yield increases varying from 81 percent at 1-inch yield from the control watershed to 140 percent at 7 inches from the control. Clearcutting one-sixth of a 900-acre watershed, where the remaining five-sixths of the watershed was placed in the best growing condition possible, increased water yield about 29 percent. In contrast, annual water yields following the individual tree selection harvest on South Fork of Workman Creek were not significantly changed by the treatment. A riparian cut of alder and big-tooth maple adjacent to streams and seeps that removed 0.6 percent of the total basal area of all trees on the 248-acre watershed did not significantly increase water yields."

Baker (1975) reported that winter streamflow from ponderosa pine forest areas in Arizona was increased most by completely clearing a watershed. All residual slash was piled in windrows, which were oriented to trap and shade snow. Increase in runoff has averaged 1.8 inches per year, a 33 percent increase over an 8-year period. The second largest response resulted from the removal of 75 percent of the timber basal area by thinning. Here also, the residual slash was piled into windrows. The average increase in runoff was 1.3 inches per year, or 19 percent for a 5-year period. Another watershed was treated by removing 32 percent of its timber in uniform, downslope strips. This treatment yielded a 1.0-inch per year increase in runoff, or a 16 percent increase over a 6-year period. Streamflow varied directly with amount of winter precipitation, but was reduced in amount proportional to both the insolation received (south versus north slopes) and the residual timber volume after cutting (H. E. Brown and others 1974).

Duration of Increased Streamflow—This depends on the magnitude of the initial increase, the type and intensity of cut, and the rapidity of regrowth. In the southeast, at Coweeta, after a clearcutting that increased flow 14 inches the first year, regrowth dropped the increase to 8 inches the 5th year, to 6 inches the 10th year, and to an estimated 1 inch at year 35 (Kovner 1957). A recutting of this watershed duplicated the 14-inch increase the first year, but the rate of increase dropped much faster, reaching 4 inches after only 5 years.[9] In the northeast, after 10 years there was only an estimated 0.5-inch increase on the Fernow watershed, where the first-year increase had been 5.1 inches (Lull and Reinhart 1967), and the 2.5-inch increase from a selection cutting was reduced to a negligible quantity in 3 years. Selection cuttings and thinnings have only transient influences on water yield because roots and canopies rapidly extend into occupied spaces.

In contrast, effects of treatment may persist longer in those western forests where regrowth is slow and increased streamflow is derived largely from differential snow accumulation. For example, 2- to 4-inch increases in flow after a 39-percent strip cutting of lodgepole pine in Colorado have persisted for 17 years and promise to persist considerably longer (Leaf 1975b). In an earlier study the ratio of increase in snow storage in cut plots to that in uncut plots remained virtually unchanged over a 24-year period (Hoover and Leaf 1967).

Minimum Selection Cuts—The minimum selection cut that will produce a significant increase of water yield in humid regions has been estimated at 20 percent of the basal area of a well stocked stand (Douglass 1967). Clearcutting 20 percent of a watershed would also increase water yield significantly. Annual cutting of smaller portions, as is done in sustained yield programs, may or may not increase water yield detectably. Berndt and Swank (1970) noted a significant increase in streamflow from a small forested basin in central Oregon following increased timber cutting. The criteria of "significance" are, of course, strictly from a statistical point of view. Once a physical increase is shown, statistical significance is not necessary criterion—if a 20-percent clearcut increases streamflow by a "significant" 2 inches, a 10-percent clearcut's 1-inch increase is equally as physically significant.

The greatest percentage increases (*table 8*) were registered in western studies, where runoff was normally low. The comparatively small increases resulting from cutting riparian areas are partly due to the small proportion of the total watershed that was treated.

The effects of different kinds of cutting on any one watershed, in connection with multiple-use programs, have received little study. A 356-acre demonstration pilot watershed developed at Coweeta includes programs for timber harvest, water yield, and recreational use. Clearcutting (for regeneration) 180 acres of poor oak-hickory stands, plus improvement and understory cuts in

[9] Unpublished report, Southeast. Forest Exp. Stn., Asheville, North Carolina.

Table 8–*Increases in water yield following forest cutting, by forest type, geographic location, and type of cutting*

Forest area (acres)	Mean precip-itation	Mean annual stream-flow	Treatment	Percent of area or basal area (b) removed	Regrowth	Water yield increases by years after treatment									
						1	2	3	4	5	1	2	3	4	5
	— Inches —					*Inches*					*Percent*				
			(1) Mixed Hardwoods, Western North Carolina												
40	72	31	Clearcut	100	Yes	14.4	10.9	10.9	9.8	7.9	66	46	29	26	31
33	75	30	Clearcut	100	No	16.8	13.0	11.7	11.4	11.2	65	–	–	–	–
23	71	24	Clearcut	100	No	5.0	3.7	2.3	4.4	3.1	–	–	–	–	–
85	81	50	Clearcut	50	Yes	7.8	6.1	5.1	4.4	3.9	–	–	–	–	–
70	79	48	Selection cut	22b	Yes	3.9	2.2	2.8	1.1	1.5	6	5	5	3	3
212	73	42	Selection cut	30b	Yes	Averaged 0.98 per year									
71	80	51	Selection cut	35b	Yes	Averaged 2.17 per year									
50	77	41	Selection cut	27b	Yes	Nonsignificant									
22	72	33	Riparian cut	12	Yes	Nonsignificant									
			(2) Northern Hardwoods, Central New Hampshire												
39	48	35	Cleared	100	No	13.5	10.8	9.4			40	29	19		
			(3) Mixed Hardwoods, Northern West Virginia												
59	57	30	Cleared	100	No	10.3					–				
85	60	23	Clearcut (except for culls)	100 (83b)	Yes	5.1	3.4	3.5	0.6	2.2	19	16	–	–	–
59	57	30	Clearcut	50	No	6.1	5.8				–	–			
38	59	26	Selection cut	36	Yes	2.5	1.4	0.3	1.2	–0.2	10	5	1	4	–
90	58	30	Selection cut	22	Yes	0.7	0.1	–0.7	–1.6	0.7	2	0	–	–	–
85	59	25	Selection cut	14	Yes	0.3	1.3	0.3	0.3	0.0	1	5	1	1	0
			(4) Oak Type, Central Pennsylvania												
106	37	13	Clearcut	20	No	2.7					17				
			(5) Douglas-fir, Western Oregon												
237	90	57	Clearcut	100	Yes	18.2	18.0				36	33			
250	90	57	Clearcut	30	Yes	5.9	6.4	5.9	11.7	8.9	16	14	19	38	24
			(6) Aspen and Conifers, Colorado												
200	21	6.1	Clearcut	100	Yes	1.4	1.9	1.0	0.8	0.5	19	27	16	12	12
			(7) Lodgepole Pine and Spruce-Fir, Colorado												
714	30	11	Clearcut	40	Yes	3.3	5.2	3.7	4.6	5.4	32	35	43	63	71
			(8) Mixed Conifers, Arizona												
1,163	27	3.2	Clearcut	16	Yes	1.2					16				
248	32	3.4	Selection cut	32	Yes	0.5	2.0	1.6	1.9	1.2	56	45	–	–	–
318	32	3.4	Selection cut	45	Yes	Nonsignificant									
			(9) Utah Juniper, Central Arizona												
323	19	0.9	Cabled, burned, seeded to grass	100	Yes	Nonsignificant									

Table 8–*Increases in water yield following forest cutting, by forest type, geographic location, and type of cutting*

Forest area (acres)	Mean precip-itation	Mean annual stream-flow	Treatment	Percent of area or basal area (b) removed	Regrowth	Water yield increases by years after treatment									
						1	2	3	4	5	1	2	3	4	5
	— *Inches* —					— *Inches* —					— *Percent* —				
			(10) Chaparral, Central Arizona												
95	26	2.2	Herbicide	90	Yes	3.4	3.0	2.6	9.8	14.2	111	292	589	451	235
46	26	2.2	Herbicide	40	Yes (grass)	3.0	0.9	1.8			299	517	223		
			(11) Oak-Woodland, Central California												
12	25	4.1	Chemical kill	100	Yes (grass)	4.0	7.9	4.0			25	65	300		
			(12) Chaparral with Woodland along Streams, Southern California												
875	26	2.5	Riparian cut	2–4	Yes	0.4					–				

(13) Ponderosa pine, Beaver Creek, Arizona

Watershed no. and year treated	Mean winter stream-flow	Treatment	Percent of area treated or basal area (b) removed	Difference between predicted and actual streamflow by years after treatment						Mean difference	
				1	2	3	4	5	6		
— *Inches* —										*Inches*	*Percent*
12, 1967	6.04	Clearcut	100	3.79	0.92	1.81	1.47	1.39	3.29	2.00	35
9, 1968	6.70	Clearcut in uniform strips	32	1.98	.61	.34	.84	1.74		1.10	16
17, 1969	7.63	Thinning	75	.85	1.45	1.51	2.93			1.68	222
14, 1970	4.71	Clearcut in irregular strips, thinning bet. strips	50	.71	.70	1.61				1.01	21
16, 1972	5.45	As above	65	5.60						5.60	103

[1] Blank = no data available; dash = no percent given in source reference.

Compiled as follows:

(1) Dunford and Fletcher 1947, Johnson and Kovner, 1954, Hewlett and Hibbert 1961, Hibbert 1967
(2) Hornbeck and others 1970, Pierce and others 1970
(3) Reinhart and Trimble 1962, Reinhart and others 1963, Patric and Reinhart 1971, files of Northeastern Forest Exp. Stn.
(4) Lynch and Sopper 1970
(5) Rothacher 1970
(6) Bates and Henry 1928, Reinhart and others 1963
(7) Goodell 1958, Martinelli 1964
(8) Rich 1968, U.S. Dep. Agric. Forest Serv. 1964a
(9) Brown 1965
(10) Hibbert 1971
(11) Lewis 1968
(12) Rowe 1963
(13) H. E. Brown and others 1974

92 acres of a cove type to increase water yield, increased streamflow the first year by 10 percent (6.2 inches) (Hewlett and Douglass 1968).

Streamflow Timing—The time of the year when streamflow increases following timber harvest has been less dealt with experimentally than total annual increases, for they have an added dimension of variability and hence are more difficult to demonstrate to be statistically significant. Examples of timing of streamflow must suffice.

At Fernow, clearcutting two watersheds in hardwood forest increased the low flow in June through October by about 1/2 to 1 inch per month (Kochenderfer and Aubertin 1975). Flow from November through May was less than or about equal to flow from the uncut watershed. Before the cutting, streamflow had dried up periodically; after treatment, flow remained above 0.3 csm (Patric and Reinhart 1971).

At Coweeta, increases in streamflow during the 7 years when one watershed was kept clearcut started to increase (compared with the control) in June, with a 0.2-inch increase, reached about 1-inch increases in the months of August through October, and increased in November and December to 1.5 inches per month; then the increases were less, until no appreciable increases were noted during April and May. Increases during the 4 driest months, August through November, totalled 4.42 inches, double the normal flow and equivalent to about one-half of the total average annual increase from the clearcutting of 8.67 inches (Douglass and Swank 1975).

At Fraser, Colorado, nearly all of the increased flow of 3.5 inches, associated with the 39-percent strip cutting, came in May and early June, with some deficit in flow in late June, about equal to the excess in early June. Recession flows during the July through September period were about equal in the cut and the control watersheds (Leaf 1975b).

At the Central Sierra Snow Laboratory, a commercial selection cut increased streamflow by 7 inches; about half of that increase was in June (Anderson 1963).

At the H. J. Andrews Experimental Forest, 80 percent of the 18-inch increase in streamflow resulting from a clearcut harvest occurred in the wet October to March season, but even in the driest month, September 1967, the increase was 0.15 inch, a 150-percent increase over that from the uncut condition. This increase is important, for it supplies an extra 87,000 gallons per day per square mile of clearcut watershed. Three-month increases averaged 0.8 inch in July to September and 3.6 inches in April through June (Rothacher 1970).

In all areas the streamflow following forest harvesting increased in seasons when augmented water supply was most needed.

Peak Flows and Stormflow Volumes

Peak flows result from the simultaneous arrival of water and waterborne debris from many sources. The effect of timber cutting on small watersheds indicates its effect on floods in general. The first eastern study of effects of clearcutting on watersheds was started in 1941 at Coweeta Hydrologic Laboratory. A 33-acre watershed was clearcut; trees were left where they fell, and sprouts were cut annually. Annual streamflow increased by an average of about 11 inches, but maximum peak discharges did not increase (Hoover 1945, Hewlett and Hibbert 1961).

More recently at Coweeta, after a 108-acre mature hardwood forest on a high-elevation watershed was clearcut, peak flows increased by an average of 9 percent. Volume of stormflow from all major storms increased by an average of 11 percent, or 0.23 inch at the mean storm runoff of 2.1 inches. Larger storms produced greater effects: a 7-day flood sequence increased the volume of storm runoff by 22 percent but amounted to less than 1 inch of direct runoff. No overland flow was observed (Hewlett and Helvey 1970).

A study of commercial logging on watersheds in West Virginia showed that the effects on storm peaks depended on the season (Reinhart and others 1963). In this study all timber of commercial value (86 percent of the total volume) was removed from a hardwood-forested watershed. Instantaneous peaks (all far less than flood magnitude) during the growing season increased by an average of 21 percent; in the dormant season they were apparently reduced by 4 percent. In a clearcut watershed storm-period discharges were more than doubled in the growing season, and snowmelt flows were reduced. In Japan, clearcutting a 6-acre watershed increased peak runoff from heavy rains about 20 percent (Maruyama and Inose 1952). No overland flow was observed in either of these studies. The Japanese, Fernow, and Coweeta studies indicate

that timber can be cut heavily without causing watershed deterioration that results in overland flow, although some peak flows increase.

In a study at the Hubbard Brook Experimental Forest in New Hampshire, an unusual treatment —removal of both forest and ground cover and prevention of regrowth—was applied. Summer peak flows increased considerably. For the six highest peak flows during June through September, 1966 through 1969, in the untreated control watershed, the peaks for a 39-acre denuded watershed averaged double the expected 49 $ft^3/s/mi^2$, with the increases for the individual events ranging from -19 to 250 percent. Most of this variation was due to differences in available storage for soil water; infiltration, apparently, was not a limiting factor. Changes in dormant season high flows not involving snowmelt were usually negligible; this indicated the similarity in soil water regimens of the treated and untreated watersheds in this season (Pierce and others 1970, Hornbeck 1973).

Clearcutting can either decrease or increase rates of flow when snowmelt is involved. Clearcutting a small watershed at Hubbard Brook increased peak flows early in the snowmelt season by as much as 35 percent (from 59 to 79 $ft^3/s/mi^2$) and decreased them as much as 66 percent (from 34 to 12 $ft^3/s/mi^2$) later in the season (Hornbeck and Pierce 1969).

Western situations are complex, and research results reflect this. First, fewer data are available from western experimental watersheds (excluding the Southwestern brushland region); moreover, for much of the region the source of floods is rain on snow or snowmelt rather than rainfall alone. At the H.J. Andrews Experimental Forest in central Oregon, along the western slope of the Cascades, no effect of clearcutting one-third of a 250-acre watershed was at first apparent on maximum flows because rainfall came mostly in low-intensity winter storms of considerable duration (Rothacher 1965a). A later report (Rothacher 1971) presents data showing that increases in storm peak flows in the clearcut watershed depended on the amount of rainfall during the 30 days before the storm. In the 1965-69 period, the peaks for 84 percent of the storms were greater in the clearcut watershed than in the uncut control, and were generally greater when the rainfall in the preceding 30 days had been less than 22 inches. Ninety percent of the 73 storms in the 1965-69 period occurred when antecedent rainfall had been less than 22 inches, but the highest peaks generally occurred when antecedent conditions had been wet. Peaks showed little or no increase after 22 inches or more of antecedent rainfall. The record shows the damping influence of the forest on peak flows from storms. Other clearcuttings in Oregon (Krygier and Harr 1972) increased peaks from fall storms by 90 percent and from winter storms by 28 percent.

At Fraser, Colorado, harvesting gave mixed results: cutting 39 percent of a lodgpole pine-spruce-fir stand in strips 1,2,3, and 6 chains wide increased peak discharge from snowmelt by 50 percent the first year; discharge the next year was 23 percent less than had been expected, and the third year it was 45 percent greater than had been predicted (Goodell 1958). For this high Rocky Mountain area, maximum peaks are less than 22 $ft^3/s/mi^2$.

Lesser cuts have lesser effects. At Coweeta, cutting a dense laurel-rhododendron understory and riparian (streamside) vegetation did not increase maximum peak discharges; and there were no overland flows (Johnson and Kovner 1954). At the Fernow, selection cuts that removed 20 to 59 percent of the original stand produced no perceptible effect on peak flows (Reinhart and others 1963).

Studies of the effects that various treatments have on small watersheds under varied conditions hardly ever tested the effects of rare events associated with large floods—large areas of frozen soil, snowmelt augmenting rain runoff, or large floods carrying debris. Furthermore the treatments usually applied do not drastically change the soils. Reinhart (1964b) pointed out that distinction should be made betweeen clearcutting steep lands and converting them to pasture or crops, and clearcutting gentle slopes without seriously compacting the soil and permitting regrowth. As long as the forest floor remains intact, most of the beneficial hydrologic effects of the forest may continue to be present.

Peak flows for several whole large watersheds in Oregon were considerably changed (Anderson 1952). Where watersheds had been logged and then burned and where 45 percent of the area was left unstocked or poorly stocked, peak flows increased by more than 30 percent.

Anderson and Hobba's (1959) analysis of forest cutting and peak flows on 54 watersheds in the Northwest approached the forest-flood relationship broadly. From data on watershed differing in

size, geology, topography, and land use, they developed equations for predicting peak discharges based on climatic and watershed variables; they then related deviations of predicted from actual discharges to difference in forest age and stocking. In those watersheds the standard cutting practice had been to clearcut large blocks and then broadcast-burn the slash. Anderson and Hobba predicted that clearcutting 1 square mile of Douglas-fir under the practice then current would increase the flood peak of rainstorms on ripe snow from a watershed by 103 ft^3/s.

The results of their analysis indicate that forest cutting does not drastically affect major floods from large basins if sustained-yield management is *properly applied* and if the logged area is promptly and fully restocked. If, for instance, 1 percent of a watershed were cut over each year, the increase in peaks would average about 9 $ft^3/s/mi^2$. This would be only a 6 percent increase in the 100-year flood, but more than 20-percent increase in the mean annual flood. On the other hand, large areas in the region studied have failed to restock after fire or logging. Further, some watershed channels might be unstable under a 20-percent increase in annual flood flow.

An analysis of snowmelt floods on watersheds on the east side of the Cascade Mountains showed that peak flows would be expected to increase by about 11 percent when one-half of a watershed was burned or poorly stocked; but logging or burning half of the watershed would be an extreme case (Anderson and Hobba 1959).

Water Temperature

Clearcutting near streams sometimes raises the water temperature sufficiently to reduce fish populations. One obvious remedy is to leave trees or shrubs along the channels, where they will shade streamflow (Brown and Krygier 1967). In West Virginia, Reinhart and others (1963) found that clearcutting raised maximum temperatures by an average of 8°F during the growing season. Temperatures exceeded 75°F several times; these temperatures would probably harm most resident trout and salmon (Lantz 1971a). In western Oregon, daily temperatures rose 2° in March and as much as 14° in September; from August 1 to 15 the mean high temperature was above 70°F. On the H.J. Andrews Experimental Forest one clear day in May, the midday temperature of water flowing for 1 hour through an exposed channel 1,300 feet long increased by 16°F (Brown and Krygier 1967).

Widespread checks of similar logged and unlogged drainages in Oregon have shown temperatures to be as much as 10° higher in logged areas where riparian vegetation was completely removed (Chapman 1962). Two years after complete clearing of a Douglas-fir forest in the Alsea Watershed, the stream temperature reached a high of 85°F—28° higher than on the unlogged control (Krygier and others 1971). On a patch-cut watershed with a buffer strip along the main stream, the maximum temperature was 61.5°F.

Exposure of the stream surface to direct solar radiation is the principal cause of increased water temperature (Brown and Krygier 1967). Understory vegetation that survives clearcutting may provide considerable protection. For example, at the H.J. Andrews Experimental Forest, clearcutting along increased maximum water temperature 4°F, but the slash burning that followed removed old protective stream cover; then the mean monthly maximum water temperature for June, July, and August increased by 12° to 14°F (Levno and Rothacher 1969).

Water temperature may be lowered as a stream flows from an exposed area into a protected one. For instance, routing an open, exposed trout stream in Wisconsin through the shade of a willow grove reduced later afternoon summer water temperatures by 10° to 11° F (Stoeckeler and Voskuil 1960). In one study of a patch-cut logging area in Oregon, water from the logged portion cooled as it passed through shaded areas downstream or was diluted by cooler water from uncut watersheds (Levno and Rothacher 1969). However, in a large-scale test in the Umpqua Basin, also in Oregon, local shading of the stream apparently did not significantly lower the temperature of water that had been warmed by exposure in a logged-over area upstream; the investigators concluded that the chief cooling effects were from inflow of groundwater (Brown and others 1971). Shading upstream tributary streams is important.

Certain forest effects on radiation and subsurface flow account for significant differences observed between large streams and small ones. On reaches of large streams that are oriented east and west, for example, longwave radiation from trees on the north side may well heat the water in summer, when the sun is high. Removing these

trees would both reduce this heating and release cooling groundwater in summer; (it might possibly increase warming groundwater flow in winter). Clearly, tree cutting alongside streams should not be prohibited on the basis of stream shading alone. The degree of shade desired may depend on the effects of the resultant stream temperature on water chemistry.

Water Chemistry

Timber felling and repeated herbicide treatment completely denuded a forest ecosystem on a New Hampshire watershed that had podzol soils derived from glacial tills. This treatment increased cation loss by 3 to 20 times; nitrate concentration in the streamwater increased from about 1p/m to 58 p/m (Bormann and others 1968). As this study continued, nitrate concentrations of as much as 80 p/m were noted, with an overall increase of about fiftyfold for the 3-year period 1967 through 1969 (Pierce and others 1970). This nitrate concentration produced a noticeable algal growth in the stream. Later, Pierce and others (1972) reported on the effect of timber harvesting, also in New Hampshire. From one clearcut area, the highest nutrient concentrations were only one-third to one-half the levels reached in the denuded watershed. "For the first 4 years of the strip-cut harvest, stream water concentrations increased by more than 7 mg/l for nitrate, 0.9 mg/l for calcium, and 0.3 mg/l for potassium. Sulfate concentrations declined by as much as 1.5 mg/l. In contrast, block clearcutting caused maximum increases of 23 mg/l for nitrate, 3 mg/l for calcium, and 1 mg/l for potassium, and an apparent decrease of 2 mg/l for sulfate." (Hornbeck and others 1975).

Other studies have shown lesser effects of watershed disturbance on nutrient discharges in streamflow. Aubertin and Patric (1974) found only a slight increase in dissolved solids during the 2 years following the clearcutting of a hardwood forest watershed in West Virginia; the maximum concentration of nitrate-nitrogen measured was 1.4 p/m.

From their studies of mineral balances for various disturbed and undisturbed watersheds, Swank and Elwood (1971) concluded that the rather drastic alterations of the forest ecosystem at Coweeta Hydrologic Laboratory had apparently not resulted in large, accelerated cation losses to drainage waters. However, they did not measure mineral presence on watersheds immediately after tree cutting or other disturbances. They reported that 10 years after a commercial logging, nitrate-nitrogen in streamflow increased by 1.9 pounds per acre per year. This is less than the 3 pounds normally added from rainfall (Swank and Douglass 1975). While forests were in various stages of natural revegetation following cutting, increased nitrate-nitrogen content in the streamflow was evident for at least 10 years after cutting, but appeared to return to "baseline levels" 20 years after the cutting. In a study in Minnesota, Verry (1972) reported no change in the composition of streamwater after clearcutting of aspen.

Fredriksen (1971) measured the loss of nutrients after timber harvesting and broadcast slash burning in old-growth Douglas-fir on the H.J. Andrews Experimental Forest. Nutrient cation discharge was 1.6 to 3.0 times that from an undisturbed watershed; annual nitrogen loss averaged 4.6 pounds per acre compared to 0.16 pound per acre from the undisturbed watershed; but average monthly concentrations never exceeded 0.4 p/m.

Hart and DeByle (1975) studied subsurface water chemistry under different slash treatments after clearcutting of a stand of 175-year old lodgepole pine. Except for a flush of nutrients soon after slash burning, they found no apparent differences in the soil solution under four slash disposal systems.

Brown's review (1972) of logging and water quality concluded that nutrient losses from Northwest forests after clearcutting were a minor short-term problem for both the terrestrial and aquatic systems. Gibbons and Salo (1973) have published an annotated bibliography of 278 publications related to the effects of logging on fish populations in the Western United States and Canada.

Summary

Timber harvesting increases water yield primarily by reducing evapotranspiration. The potential for increased yield is greater where precipitation is higher. Where rainfall and seasonal evapotranspiration are important, the situation is different from those involving snowfall and changes in snow interception, distribution, and melt rate.

In areas where snow is not important, the increase in water yield the first year after cutting

appears to be proportional to the percentage of basal area cut, and the water yield increases mainly during and immediately after the growing season. Increases diminish as the forest regrows; they may continue for 10 years or less where regrowth is rapid and soils relatively shallow. Where regrowth is slow or where soils are deep, increases may persist much longer.

Water yield increases from timber harvesting in snowpack areas occurs mostly in the spring or early summer period of snowmelt discharge; the increases following harvesting persist longest where vegetation recovery is slow.

The effect of timber harvesting on floods varies. Several factors limit increases in flood peaks and flood runoff even after clearcutting, the harvest method with the greatest impact. Timber harvesting does not generate overland flow except where it disturbs the forest floor. Overland flow from logging roads and other disturbed areas is partly absorbed by infiltration into adjacent areas, especially where logging operations are well planned and executed. The effect of cutting on flows is diminished, especially in regions where precipitation is ample and well-distributed, as regrowth reestablishes interception and soil-water retention opportunity. Under sustained-yield management or where forest holdings are many and small, only a small proportion of any sizable drainage is likely to be cut over at one time.

The fact remains that clearcutting can increase flood flows, especially when soil disturbance is widespread, where regrowth is slow or covers only part of the area, or when snowmelt contributes a sizable portion.

Several conditions accentuate the problem in the West as compared to the East: These include slow regrowth in many areas because of low rainfall, especially in the growing season; greater volumes of timber and bigger logs in other areas, resulting in the need for bigger equipment and greater soil disturbance; and the practice in many areas of burning debris after logging.

Timber harvesting and its associated roads can, have, and often still do cause serious erosion and sedimentation. The amount of damage on site, in local streams and downstream, varies widely with topography, climate, soils, and the amount of soil disturbance, which depends on such things as care in logging, intensity of cut, and the equipment used. For many areas, responsible logging can keep damages within bounds, but better practices than those applied in many areas in the past will be required.

In some steep, fragile areas, conventional logging may not be possible without intolerable damage. Use of the skyline crane, or of balloon or helicopter logging (assuming their use is demonstrated to be practicable) may make timber harvesting feasible in these areas. Even with such techniques the susceptibility of stream banks to scour and sliding induced by increased streamflow following timber harvesting will need to be appraised.

For many of the same reasons we discussed with respect to timber harvesting and floods, the effect of timber harvesting on erosion, including its effect on water quality, is generally a greater problem in much of the West than it is in the East.

Timber harvesting sometimes increases stream water temperatures to the detriment of cold-water fish. Stream temperatures can be kept cool by preserving all or part of the vegetation shading the stream channel. Increased water temperatures may sometimes stimulate a favorable production in the food chain.

Research to date indicates that clearcutting does not increase volumes of dissolved solids enough to lower water quality below drinking water standards. However, nitrogen discharge may frequently, though temporarily, exceed the concentrations necessary to increase the growth of algae. It has been reported that less than 0.5 p/m of nitrogen may cause such growth (Tarrant 1972). Of the studies so far conducted, only those on podzol soils in New Hampshire indicate that clearcutting may diminish the nutrient capital of the soil. Partial cuts, of course, have less effect. Further research on this problem is needed and is in progress at most forest experiment stations and at several universities.

Regeneration and Tree Planting

Forest regeneration and subsequent growth increase interception and, particularly, transpiration. Whether regeneration increases infiltration capacity depends on the soil's initial capacity. Water yield, peak flow, erosion, and sedimentation will gradually be reduced as trees grow in height and density.

Interception

The growth of conifer plantations over a period of years may substantially reduce water yield by

increasing interception (Swank and Douglass 1974). Take, for example, an annual rainfall of 41 inches consisting of ten 1-inch storms, thirty 0.5-inch, and eighty 0.2-inch. According to Helvey's (1967) equations, a 10-year-old eastern white pine stand would intercept 8.3 inches of water, a 35-year-old stand would intercept 9.9 inches, and a 60-year-old stand would intercept 13.1 inches—a reduction of water available for annual streamflow amounting to 4.8 inches at the end of a 60-year period. The oldest pine stand intercepts twice as much as the youngest, and twice as much as mature hardwood stands. From a single flood-producing 2-inch storm, for example, a 10-year-old white pine stand could intercept about 0.17 inch, a 35-year-old stand, 0.23, and a 60-year-old stand, 0.34 inch (Helvey 1967).

Infiltration, Overland Flow, Erosion, and Sedimentation

Increased rates of infiltration and diminished overland flow make more water available for evapotranspiration so less for streamflow. This change normally reduces both water yield and storm discharges. In the East, this effect is most pronounced in the growing season, when streamflow is much less than in the cooler months.

Infiltration, overland flow, and , to some extent, surface detention change as a plantation matures. The significance of the change depends on the surface cover and infiltration capacity at the time of planting. Planting a bare, eroding site may increase infiltration in 10 years to the point where overland flow and erosion practically cease (Ursic and Dendy 1965). On the other hand, mechanical site preparation in some areas of the South is reported to cause severely accelerated erosion (Dissmeyer 1976).

Old fields may support enough invading vegetation to stabilize soil without trees. In West Virginia, measurements of streamwater quality showed that farmlands, abandoned for two decades, have healed naturally so the areas produce only slightly higher turbidities than undisturbed forest land (Hornbeck and Troendle 1969).

In Tennessee, planting about one-third of the severely eroded 1,715-acre White Hollow watershed, mostly to pine, and permitting natural regrowth on the rest of the watershed reduced the sediment load following the average storm from 7.3 tons in 1935-36 to 0.3 ton in 1954-55, a reduction of 96 percent. The reduction each year averaged about 15 percent of the previous year's sediment load (Tennessee Valley Authority 1961). Planting two-thirds of the Pine Tree Branch watershed in Tennessee reduced the sediment load from 24.3 tons per acre in 1942-45 to 7.6 in 1946-50, to 2.2 in 1951-55, and to 1.1 in 1956-60, an overall reduction of 95 percent (Tennessee Valley Authority 1962). In both of these watersheds, installation of check dams and other erosion-control measures was responsible for an undetermined portion of the improvement.

Planting loblolly pine in northern Mississippi sharply reduced sedimentation. Annual rates of erosion loss on four different types of planting sites were:

Land Use:	Mean	Range
	Tons/Acre	*Tons/Acre*
Pine plantation (22 yrs old)	0.02	0.00 to 0.08
Mature pine and hardwoods	0.02	0.01 to 0.04
Abandoned fields	0.13	0.01 to 0.54
Cultivated lands	21.75	3.28 to 43.06

The pines had been planted on abandoned fields where erosion had removed an estimated 2 feet of the surface and had cut gullies 5 feet below the level of the remaining soil (Ursic and Dendy 1965). The planting has reduced erosion to near the geologic norm for forests in the area.

Six years after trees were planted on eroded cropland at Coshocton, Ohio, they established a nearly complete ground cover, sheet erosion practically ceased, and small gullies were stabilized (Harrold 1961).

Soil-Water Storage

Major increases in detention storage may also follow forest establishment and growth. For instance, on an experimental watershed at Coshocton, Ohio, the volume of noncapillary pore space in the surface 7 inches of three types of soil under three kinds of cover was as follows (Harrold and others 1962):

	Idle land	Pine cover	Hardwood cover
	Percent (by volume)		
Soil type:			
Keene silt loam	11.4	14.7	16.5
Muskingum silt loam over:			
Sandstone and shale	14.9	23.4	23.1
Sandstone	21.3	25.2	24.4

Thus the two forest stands had from 15 to 55 percent more detention storage space than the idle land.

Reforestation of old fields, however, may not quickly restore detention storage everywhere. In South Carolina's Piedmont, Hoover (1950) found detention storage of 4 inches in the upper 24 inches of undisturbed hardwood forest soil, whereas under a pine stand 25 to 30 years old with a sandy plow horizon, detention storage was 1.2 inches; detention storage totaled 17 and 5 percent by volume, respectively.

Evapotranspiration and Streamflow

Evapotranspiration increases as regeneration develops. After two clearcut watersheds at Coweeta were planted to white pine, streamflow steadily decreased (and evapotranspiration — including evaporation of intercepted water — increased). The cleared plantations averaged 2.5 and 9 inches more water yield, respectively, the first 6 years after planting; but once the crown began to close the rate of increase declined to 1 to 2 inches per year, until at age 10 years the first watershed had 3.7 inches less yield, and at the age of 11 years the second had 1.3 inches less (Swank and Miner 1968). At age 15 years both watersheds had about 7.9 inches less streamflow than had been predicted if the watersheds had remained in hardwoods (Swank and Douglass 1974).

Streamflow from a 491-square-mile watershed in the Adirondacks decreased 7.7 inches (or evapotranspiration increased) over a period of 39 years, as the forest density and crown cover of conifers increased (Eschner and Satterlund 1966).

The amount of reduction in yield must obviously depend on the proportion of the watershed planted. If we extrapolate the decreases in water yield [*table 9*] for partial plantings in Ohio, western Tennessee, and New York to those for complete planting, the reduction would range from about 6 to 9 inches for four of the five examples, and to 19 inches for the New York watershed where 35 percent of the area was planted. The decrease in New York may have been greatest because snow was an important meteorological factor there.

Peak Flows

Increases in interception, infiltration, and opportunity for soil-water storage concurrent with plantation growth may sharply reduce peak discharges. This reduction varies with the type of cover before conversion, and the proportion of the watershed planted; reductions differ also between seasons of the year. The results of four studies appear in *table 10*. The reduction in peaks of 16 to 66 percent in the New York study was attributed to the lower melt rate of snow shaded by the conifers in winter; some of this reduction, however, could have resulted from greater retention of soil-moisture provided by increased transpiration during the preceding growing season.

Planting the Tennessee watersheds reduced summer peaks by amounts ranging from 62 to 92 percent. The much greater reduction in winter peaks on the Pine Tree Watershed, compared to those on White Hollow, may be due to the relatively greater area planted and to the smaller area of the watershed.

A planted forest appears to be more effective in reducing peak flows than a cutover forest is in increasing water yield. This apparent difference probably arises from the establishment of forest floor and improved soil conditions in the new plantation, whereas merely cutting the forest trees does not, by itself, usually destroy the forest floor or the hydrologic attributes of the soil. Then too, the cut forest often recovers to some form of vegetation before the soil hydrologic attributes deteriorate sufficiently to affect most flood-producing events.

Planting trees, especially conifers, effectively reduces peak flows. Planted land is likely to receive better protection from fire and grazing than idle land—protection that will maintain flood-control benefits.

Above-normal temperatures in the spring occasionally cause abnormally rapid melting of snow accumulated under plantations; and the greater the depth of snow in the forest, the more it may add to above-normal peak flows. Such flows are most damaging when they are well synchronized, which means that heavy flows from all parts of the watershed arrive downstream at the same time. Such watersheds require desynchronization of peak flows; this is provided by the juxtaposition of open and forested lands such as now exists in the northern Allegheny Plateau of New York (Satterlund and Eschner 1965); a mixture of conifer and hardwood areas may also desynchronize potentially destructive peak flows.

In forest regeneration and tree planting, site preparation may include measures that lay bare

Table 9—*Effects of reforestation on water yield from varied conversion plantings in Ohio, Tennessee, New York, and North Carolina*

Location	Forest cover before planting	Pretreatment mean annual . . . Precip-itation	Stream-flow	Conversion planting by extent and type	Reduction in water yield for given year
		— *Inches* —			*Inches*
(1) Ohio	30% hardwoods	38	12	71%, pine	5.3 (9 yr)
(2) Western Tennessee	23% hardwoods	50	10	65%, mostly pine	3 to 6 (16 yr)
(3) Central N.Y. (3 watersheds)	1. Mixed hardwoods	38	21	47%, conifers	4.2 (24 yr)
	2. do.	41	24	58%, conifers	6.8 (23 yr)
	3. do.	41	25	58%, conifers	5.1 (23 yr)
(4) Western Tennessee	65% mixed hardwoods and pine	47	18	34%, mostly pine	0
(5) Chenango River Basin, New York	Abandoned farmland	45	25	7%, conifer plantations (10% second growth hardwoods)	1.0 (42 yr)
(6) Western North Carolina	Hardwoods:				
	Watershed 1	68	31	100%, white pine	5.6 (10 yr)
	Watershed 17	76	27	100%, white pine	10.9 (11 yr)

Compiled as follows: (1) Harrold and others 1962; (2) TVA 1962; (3) Schneider and Ayer 1961; (4) TVA 1961; (5) Muller 1966; (6) Swank and Miner 1968.

the mineral soil to improve the seedbed for natural seedfall; it could include also any methods for removal of vegetation that would compete with the trees being planted. These practices may promote erosion and sedimentation and therefore must be used with care. Wherever dense stands of brush have been removed, increased streamflow must be expected until vegetation is reestablished and develops.

Summary

Regeneration of forest stands, either by natural seeding or by planting trees after timber harvest, reverses the effect of harvesting. Water yield, stormflow, erosion, and sedimentation are likely to be reduced. The rate of this reduction depends upon the rate of growth of new herbaceous and woody vegetation, which is influenced by climate, the success of regeneration measures, and other factors.

Planting of previously unforested areas can have a much greater effect than reforestation; the difference in effects depends largely on the extent to which the prior cover protected the site and utilized available water in evapotranspiration.

Type Conversions

Conversion from one vegetation type to another may be advocated for a variety of reasons, including greater timber production or increased water yield. Conversion may have important hydrologic effects, but firm data are scarce for many of the different possible conversions.

Most tree planting in the East has been conifers, even where hardwoods were the original cover. Studies in Michigan and North Carolina showed that conifers use more water than hardwoods. In northern Michigan the annual yield of water from a jack pine plantation was 2.6 inches less, and red pine with an oak overstory 3.0 inches less than the yield from a deciduous stand (Urie 1966, 1967). At Coweeta two watersheds replanted to white pine yielded about 7.9 inches less water after 15 years than the original hardwood forest. Most of this reduction occurred during dormant seasons, but some occurred in each month (Swank and Douglass 1974). However, streamflow increased during the first 6 years by an average of 2.5 inches;

Table 10–*Effects of reforestation on peak flows from selected experimental watersheds*

Watershed location	Area	Watershed condition		Effect on peak flows
		Before treatment	After treatment	
	mi^2			
(1) Shackham Brook area Near Truxton, N.Y.	3.12	25% deciduous 1% coniferous 74% pasture and crops	27% deciduous 57% coniferous 16% pasture and crops	From 1939 to 1957 peak flows were reduced by 41% ranging from 66% in November to 16% in April.
(2) White Hollow Watershed Mason Co., Tenn.	2.68	66% poorly stocked mixed hardwood and pine 4% cultivated 4% cultivated 26% abandoned land	100% mixed hardwood and pine	From 1935-36 to 1942-49, summer peak discharges were reduced from 73% to 95%, dependent on initial soil wetness and rainfall intensity. Winter peaks were reduced from 0% to 28%, depending on amount surface runoff.
(3) Pine Tree Branch Watershed, Henderson Co., Tenn.	0.14	23% deciduous 16% cultivated 19% pasture 50% idle 2% miscellaneous	33% deciduous 65% coniferous 2% miscellaneous	From 1941-45 to 1951-60, summer peaks were reduced 92% to 97%, winter peaks 71% to 92%, depending on rainfall intensity and soil wetness.
(4) Watershed 172 Coshocton, Ohio	0.068	29% woodland 51% pasture 20% idle	43% natural woodland 57% forest plantation (pine and locust)	From 1938 to 1957, average growing season peaks were reduced by 59%; dormant season peaks were reduced by 69%. (Mean peaks were 35 and 46 ft^3/s/mi^2 in growing and dormant seasons, respectively.) No effect was found on peaks from extreme storm occurrences (data were insufficient for rigorous analysis).

Compiled as follows: (1) Schneider and Ayer 1961; (2) TVA 1961; (3) TVA 1962; (4) Harrold and others 1962.

so 15-year average reduction was about 1.7 inches per year. Under intensive management, including periodic thinnings, intermediate harvests, and final cutting, the water yield will be partly restored and the value of pine products may justify conifer planting, even if it causes some water loss.

Brushland has been converted to grassland range in California to increase water yield and forage production. Differences in water yield may be chiefly a matter of rooting depth, since the shallower rooting grass transpires less moisture than trees. Other possible differences in water use between grass and forest are the lower height and smoother surface of the grass, which reduce both energy absorption and vapor exchange. The shorter growing season of grass also influences its use of water. When precipitation is adequate to charge the soil mantle, the potential annual increases

from conversion of chaparral to grassland range can amount to 1.2 inches for a 3-foot soil, 3 inches for a 6-foot, and 6 inches for a 9-foot soil (Bentley 1967). Rowe and Reimann (1961) showed that increases occurred only in years when rainfall exceeded 25 inches and only when deep rooted weedy herbs were not present. Root depth was the key to difference in water use between trees and grass in western Colorado. Quaking aspen used 19 inches of water, spruce 15, and grass 9 inches during the growing season. Use of moisture by grass was confined almost entirely to the upper 4 feet of the 8-foot-deep soil (Brown and Thompson 1965).

In Arizona, conversion of brush to grass increased streamflow from small watersheds by one-third so that present annual water yield is as much as 5 inches depending on soil depth and amount of precipitation (Ingebo and Hibbert 1974). In another Arizona study (Longstreth and Patten 1975), conversion from chaparral to grass increased water discharge by four times, but, except for nitrogen, ion concentrations were similar with and without conversion; nitrate reached 4 mg/liter under grass, but was rarely detectable under the deep-rooted chaparral.

Potential increases in water yield diminish as regrowth increases. Bulldozing woodland brush at high elevation in California saved 4 to 5 inches of soil moisture the first year for soils 4 feet deep; by the fifth year no saving occurred because of use by brush sprouts (Anderson 1963). A further benefit was delay in snowmelt; in the bulldozed area the melt in the April 1 - May 10 period was 3 inches less than it had been prior to brush treatment. When the forest becomes established in this area it promises 7 inches of delayed snowmelt compared with the brushfield.

Grassland converted from steep forest and brushland is a principal source of increased suspended sediment in the streams of northern California (Wallis and Anderson 1965). Conversion to grass of 15 percent of the steep forest lands was followed by a 4.7-fold increase in sediment discharge. Erosion the first year after a controlled burn in Los Padres National Forest produced 3 tons of sediment per acre from steep slopes; runoff water contained only traces of nitrogen, but 13 lbs/ac was lost in sediment (DeBano and Conrad 1976). Areas proposed for conversion to grass cover should never include steep slopes or shallow or infertile soils liable to soil erosion or slippage.

Mass slope instability under grass on steep slopes is a major problem (Rice and others 1969, Rice and Krammes 1971). On the San Dimas Experimental Forest, areas of burned brush converted to grass had 8-fold increases in landslides and sediment production (Rice and Foggin 1971). Similar consequences were noted in a northern California study.[10]. Surveys have shown that 25 to 30 percent of the chaparral area in southern California and Arizona can be classed as potentially productive for forage (U. S. Senate Sel. Comm. Natl. Water Resour. 1960b). However, these estimates were made without benefit of recent research results, either on methods of conversion or on the consequences of conversion to grass.

At Coweeta, a 22-acre forested watershed was clearcut, fertilized, limed, and seeded to grass—Kentucky 31 fescue. The first-year water yield was 0.67 inch less than the yield from the original forest. After a decline in reserves of fertilizer and in the production of dry matter, water yield increased until by the fourth and fifth years it was averaging about 5.8 inches more than yield from the original forest, an 18-percent increase. In the sixth year the area was refertilized; the grass responded vigorously, and the increase in water yield dropped to near zero (Hilmon and Douglass 1968). Thus grass may present a water-saving alternative in forest areas that have suitable soils and topography. Murai (1975) noted possible adverse results of conversion from forest cover to grass. He reported that whereas natural grassland had an infiltration capacity of 40 to 70 percent of forest land, a forested area converted to grass cover had infiltration capacity of only 20 to 25 percent of its capacity when in forest. Contemplated conversion of forest land to grass should be considered with due respect to the possible adverse hydrologic consequences.

The conversion of forest to agricultural or urban use causes major hydrologic changes, but the problems created are in agricultural and urban hydrology rather than forest hydrology, and therefore are not discussed here. However, where such conversions are being made, the hydrologic and other benefits of keeping some portion of the area in forest cover, and properly protecting and managing it, should not be overlooked.

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[10] Burgy, R. H., and Z. G. Parazifirou. 1971. Effect of vegetation management on slope stability. (Unpublished report on file, Dep. Water Sci., Univ. Calif., Davis.)

Fertilizers, Herbicides, and Insecticides

Intensive forest management may include the use of fertilizers, herbicides, and insecticides. These materials can contaminate streamflow and groundwater, but proper control of treatments can substantially reduce this threat to watershed values. The future role of chemicals in forestry has been discussed by Tarrant and others (1973). They predicted that selective, less persistent chemicals will continue to be used in forest management, but they state that chemical applications basically are treating symptoms of unhealthy ecological conditions.

Fertilizers

Fertilizing forest to increase growth has become accepted practice in some parts of the country. More forested areas have been fertilized in the Southeast and Pacific Northwest than elsewhere. In the Pacific Northwest about 300,000 acres of forest land are fertilized annually (Moore 1974). Fertilizers may be used commonly in the future, but their effect on water quality must be considered; a few studies have already been conducted.

Heikurainen and Paivanen (1970) reported the effects of forest thinning, clearcutting, and fertilizing on the hydrology of drained peatland in Finland. The groundwater table rose as much as 6 inches in summer after the heaviest cutting. Fertilizing, with associated growth stimulation, lowered the groundwater table by 2 to 3 inches, and there was an associated decrease of 24 to 28 percent in outflow. Moore (1975) fertilized a 169-acre forested watershed with 426 pounds of urea (200 pounds nitrogen) per acre and found little effect on water quality. Only one-half pound per acre was discharged in streamwater the first year; maximum concentrations found in the streamwater were 1.4 p/m of urea and less than 0.2 p/m for nitrate-nitrogen. Aubertin and others (1973) applied 500 pounds of urea (235 pounds nitrogen) per acre in May to a 74-acre forested watershed in West Virginia. In the year following fertilization, nitrogen in the streamflow was increased only about 18 percent. Ammonium-nitrogen concentration was usually below 1 p/m and always below 2 p/m. Nitrate-nitrogen concentrations remained relatively low (below about 5 p/m) through most of the summer but rose as streamflow increased in the fall and reached 14 p/m during one storm period in September. Bengston's excellent review of forest fertilizing (1972) includes a discussion of its impacts on the environment.

On forested watersheds where overland flows are minimal, fertilizing is not likely to affect water quality adversely if direct application to streams is avoided and if application is restricted during spring snowmelt and heavy storms (Moore 1974). However, because different fertilizer materials are being applied at various rates during the current development of fertilization practices, streamwater should be monitored as a safeguard.

Herbicides

The risk of contamination from herbicides is a legitimate cause for concern. However, in many management situations their careful use has prevented problems. For instance, hand spraying streamside vegetation in New Jersey, Pennsylvania, and California, and basal spraying, stump treatment, and foliage spraying in West Virginia did not contaminate flow downstream (Krammes and Willets 1964, Lull and Reinhart 1967). However, after the experimental application of fenuron to part of a chaparral watershed in Arizona, relatively low concentrations of the herbicide persisted in the stream water for 2 full years (Davis and Ingebo 1970). After helicopter spraying in Oregon some herbicide was found in all streams in the sprayed area. This kind of contamination can be held to a minimum by avoiding direct application to large, slow-moving streams and marshy areas (Oreg. State Dep. Agric. 1967). The drift of herbicides during aerial spraying over western watersheds has caused major concern.

After considering the toxicity of the herbicide 2,4,5-T to animals, its biological degradation in the soil, and its incidence in streams after spraying, Montgomery and Norris (1970) concluded: "The hazard of 2,4,5-T in the forest environment is low when used according to tested procedures." Herbicides applied as aerosols are likely to drift; so this method of application is no longer recommended. Herbicides can be used to control vegetation but should be used only where known to be safe. Research may answer questions about safety that are now causing concern. Kunkle (1974) published some guides for proper use of herbicides and insecticides.

Insecticides

Insecticides also are used as tools in forest management. They pose a greater potential hazard

to wildlife and man than herbicides. Present policy emphasizes minimal use of insecticides, the use of less persistent ones, substitution of biological controls wherever possible, and evaluation of environmental effects before insecticides are applied.

Fire

Burning the forest can increase both water yield and stormflow discharge. The amount of increase depends on the intensity, severity, and frequency of burning and the proportion of the watershed burned. Where much of the foliage is destroyed, interception and evapotranspiration are reduced; where the organic layers of the forest floor are consumed and mineral soil exposed, infiltration and soil-water storage capacities can be reduced. Fire may have greater effect on peak flows and erosion than harvesting, because it destroys the protective influence of the forest floor on a watershed that is completely burned.

Fires range from the intense conflagration that consumes everything in its path to the light surface fire that consumes only recently deposited, undecomposed leaf litter on the forest floor, and the range in effects of fire is just as great. Crown fires are generally more destructive than surface fires, but under some conditions a severe surface fire can kill all the trees and understory vegetation. The duration of fire effects ranges from a very short period to many decades, depending on the extent of the fire itself and the rate of recovery, which is influenced by both natural conditions and remedial measures applied by man.

Occasional fire has always been a natural occurrence in many forests; many present-day forest types owe their origin and perpetuation to fire. Thus what we call normal hydrologic behavior of many forested watersheds already incorporates some effects of fire.

Forests in the United States experienced a long period when fire frequency was greatly increased by actions of man. To some extent this is still true, but current prevention and control efforts generally keep fire from having the serious impact on forests that it had before settlement. When fires are less frequent, they are likely to be more severe because of the larger accumulation of fuel on the forest floor.

Forest areas are sometimes burned over to attain timber management or other objectives. These burns, called prescribed burns, are generally made during periods when burning conditions are moderate so that the impact on the forest floor and understory vegetation is less severe than the effects of large wildfires. No one has yet accurately determined or clearly documented (1) what forest types and soil conditions, (2) what sequences of weather conditions, or (3) what frequency of controlled burns will achieve the usual management objectives without also having adverse effects on watershed values and watershed protection. The needed evaluation is complicated by the sporadic nature of conflagrations, the infrequency of major storms, and the wide variation of watershed recovery potential after fires.

Recovery from fires, usually surface fires, may be rapid in the East—typically within a few years; regrowth after severe burning can be very slow—requiring decades in some forests.

Interception

Forest fires usually are classed as surface or ground type, or as crown fires; both types may kill trees. Severe fire may drastically reduce interception, even more than a timber harvest. As fire consumes or kills the principal intercepting surface, it can reduce summertime interception by hardwoods and conifers, respectively, from about 10 and 20 percent of rainfall to less than 5 percent. Most surface fires have little or no effect on canopy interception, but in Hawaii, a 17-percent increase in stormflow after the burning of fern cover from a watershed was associated with a reduction in "storage that was readily available for evaporation, such as interception storage." Infiltration and percolation were unaffected by the burn (Anderson and others 1966).

The maximum reductions in interception following surface fires are suggested by the amount of storage water in the litter of forest floors, discussed in the section on evaporation.

Infiltration, Overland Flow, Erosion, and Sedimentation

Infiltration, surface detention, and overland flow may or may not be affected by fire. In the humid East, fires severe enough to cause serious damage are rare under present forest protection. In the past, severe fires have reduced some surface areas, especially at higher elevations, to almost barren rock. In the drier West, the effect of fire is greater than in the East. The slow recovery of vegetation after fire at high elevations there results in greater accumulation of snow and more rapid melting, both of which add to hazards of spring

flooding. Hot summer fires in the West can reduce the forest floor to ashes and thus set the stage for higher peak flows and greater water yield as overland flow.

The first year after a wildfire burned over three experimental watersheds in Washington, maximum streamflows were double the rate of flows before the fire, and debris flows in the same area were from 10 to 28 times as great as they were before the fire (Klock and Helvey 1976). In northern Montana, plot studies of runoff and erosion after broadcast burning following logging of mixed conifer stands recorded that runoff from snowmelt increased and remained high for four years after the burning, but erosion dropped back to normal volumes by the third year (DeByle and Packer 1972). Nutrients were lost in runoff only during the first year after the burning. Cole and others (1973) found losses from leaching were three to four times higher in slash-burned areas than in clearcut areas that were not burned.

Three studies of the effects of repeated burning on rates of infiltration in plots in the Ozark Mountains in Missouri showed that rates of infiltration into unburned surfaces were from about 60 to 800 percent higher than into soils of burned plots (Arend 1941; Auten 1934; Paulsell 1957).

Other research has shown less notable differences. Burns (1952) found that moderate burning on sandy soil in the pine barrens of New Jersey had little effect on infiltration; it increased the time required for 1 liter of water to infiltrate from 140 to 150 seconds. Hodgkins (1957) found no significant difference in infiltration rates between burned and unburned areas in loblolly-shortleaf pine stands in Alabama.

In northern Idaho, under an unburned stand of western hemlock with a duff layer about 2 inches deep, the infiltration rates exceeded the rates of applied rainfall, 3.5 to 5.2 inches per hour. In a stand broadcast-burned 17 years earlier, which had a thin and discontinuous layer of duff, the infiltration capacity was 2.8 inches per hour. However, this rate was exceeded only occasionally by natural rainfall (Holland 1953). In the Pacific Northwest, where thousands of acres of logging slash are burned annually for fire protection, slash burning has little effect on the hydrologic properties of the soil; its major impact is limited to severely burned spots that occupy only 3 to 8 percent of the total area (Tarrant 1956, Dyrness 1963). In the Idaho granitic batholith wildfire and slash-burned area reburns have been major problems (Megahan and Molitor 1975). Present policies designed to abate air pollution are leading to revision of slash-burning practices.

Burning affects overland flows very differently on different cover types. In the northern California brush zone, there was no consistent difference in runoff from sparsely covered chamise plots before and after burning; but runoff increased by a factor of 1.35 to 14.8 after burning of manzanita, oak, and shrub oak types (Anderson 1949a).

The effects of fires on both runoff and erosion depend on their frequency. Frequent fires can remove most of the protective cover, and thereby increase the potential for overland flow. In North Carolina, overland flow from a woodland plot burned twice a year for 9 years increased rapidly at first (Copley and others 1944). After 5 years' burnings, the annual runoff from the burned plot levelled off at an average of about 8 inches, equivalent to 22 percent of the rainfall (compared to less than 0.01 inch from the unburned control plot). The woodland plot burned twice annually lost 0.01 ton of soil per acre the first year, and 0.03 the next year; by the fifth year the loss was 3.90 tons; the next 4 years the loss averaged about 5 tons per acre—a substantial amount, but only about one-fifth the loss from plots where cotton and corn were growing. The unburned plot consistently lost only 0.01 ton per acre per year.

In the loessial upland of Mississippi, Meginnis (1935) found that for 103 rainstorms annual burning of a scrub oak forest resulted in overland flow from 54 storms, compared to 32 from a mature oak forest unburned for at least 7 years. In the 2-year study, less than 1 percent of the rainfall appeared as runoff in the mature oak plot, whereas the scrub oak plot produced 8 percent. Erosion from a scrub oak plot, typical of areas subject to severe cutting and annual fires, amounted to 0.33 ton per acre per year as compared to 0.02 ton from a mature oak forest. Conditions under the scrub oak were somewhat better than those in the North Carolina study; small quantities of litter were present but the mineral soil was exposed in many places (Meginnis 1935).

The development of a nonwettable layer of soil a little below the surface following fire is being intensively studied in California and elsewhere, and is discussed below in the section on southern California and Arizona chaparral. The extent to which this phenomenon occurs in the rest of the United States is not known; it probably occurs elsewhere (Bond 1968, DeBano 1969, Meeuwig 1971, Scholl 1971) but almost certainly with less

noticeable consequences than in the chaparral, where the effect of fire on floods is evident. However, this nonwettability of soil may promote overland flow in any area that has the combination of periodically repeated fires, coarse-textured soils, and high intensity rainstorms.

The effects of forest wildfire and prescribed burning on erosion and sedimentation depend on the severity of the burn, the erodibility of the soil, the potential for recovery of the vegetation, and the kind of storms that follow the fire. In humid forest regions, occasional wildfire and infrequent prescribed burning do not produce overland flow and hence do not cause erosion. Thus summer prescribed fires in Georgia's lower Piedmont, which killed 86 percent of the understory hardwood stems and provided for successful regeneration of pine, had negligible effect on soil movement. "Almost all of the decomposed litter was left to protect the soil; even some of the partially decomposed litter remained unburned. The top layer of mineral soil also has organic matter incorporated in it and is receptive to rainfall absorption" (Brender and Cooper 1968).

Studies of prescribed burning on much drier ponderosa pine sites in California and Arizona showed no noticeable effect on overland flow and erosion. In both studies a sufficient layer of organic material remained after the fire to protect the soil (Biswell and Schultz 1957, Cooper 1961). The bulldozer trails created in controlling the burns contained some overland flow. In a mixed-conifer forest, prescribed burning increased both surface runoff and erosion (Agee 1973). In another study in Arizona, erosion occured only where less than 60 percent litter cover remained after burning (Pase and Lindenmuth 1971).

Massive wildfires in western forest regions have accelerated both erosion and sedimentation. In northern California watersheds, a 10-year average of 34 acres per square mile of wildfire increased sediment discharge 2.3 times (Wallis and Anderson 1965). Seventeen years after the Tillamook Burn in the Wilson River Watershed of Oregon, the annual rate of sediment discharge was 500 tons per square mile, five to eight times that of nearby unburned forested watersheds having similar geology (Anderson 1954).

Similarly, presence of brushfields at high elevations in the Sierra Nevada in California has been attributed to the spread of autumnal fires set by sheepmen to "green up" the next season's growth. Recent analysis shows those brushfields produce 55 percent more sediment (measured as deposition in reservoirs) than coniferous forest stands (Anderson 1974). In southern California too, "old fires," fires that had burned 15 to 60 years earlier, were still accelerating reservoir deposition. During the March 1, 1938 flood, thrice-burned areas had sediment rates four times those of areas that had no old fires (Anderson and Trobitz 1949).

When trees, ground vegetation, and forest floor are completely destroyed by fire, high-intensity rainfall usually produces great quantities of sediment. On the 242-acre Dog Valley experimental watershed established on such a burn on the east side of the Sierra Nevada near Reno, Nevada, a single storm produced 16,100 cubic feet of sediment, or about 2,500 tons per square mile. Nearby unburned areas produced scarcely a trace of sediment (Copeland 1965). During the same year, only low-intensity rain and snow fell in another part of the burn; maximum sediment concentration in the streamflow did not exceed 78 p/m (Anderson 1962a).

Substantial erosion followed an intense fire on 60 acres of a 318-acre watershed in the South Fork of Workman's Creek in Arizona. The fire consumed litter and ground vegetation and killed all but a few ponderosa pine; it was followed by a 3.8-inch rain, one of the heaviest on record in that area. The burn was confined to the flattest slopes; unburned vegetation trapped and held half of the sediment, and tree growth and rocks prevented gully formation. In spite of these favorable conditions, sedimentation was about 1 acre-foot, equivalent to about 33 tons per acre of burn (Rich 1962).

Hot fires are not always followed by great yields of sediment. Soil type, revegetation, topography, and meteorological events may nullify fire effects on erosion. Erosion indicators on a fire-denuded area of the Douglas-fir region show that the exposed "shot-loam" soil maintained sufficient infiltration capacity to prevent most overland flow; growth of vegetation during the first year after the fire provided additional effective control (Sartz 1953).

Soil-Water Storage

Fire reduces the capacity for soil-water storage when humus layers and organic material in the mineral layers are burned, or when soil exposure augments the oxidation of organic matter. In the

surface 2 inches of soil, severe surface fires can reduce the capacity about 1/4 inch (Dyrness and others 1957). When an overlying 2-inch layer of humus has been destroyed, the total reduction of water storage capacity would be about 1 inch. Obviously crown fires drastically reduce evapotranspiration and opportunity for soil-water storage; the result is similar to that of cutting the forest.

Evapotranspiration

A light ground fire may have little or no effect on evapotranspiration; a hot crown fire may have an effect equal to or greater than clearcutting, for it may destroy the forest floor, the tree canopy, or both. A reduction of interception and transpiration may be partly offset by increased evaporation from the forest floor, particularly if seasonal rainfall comes as many low-rainfall storms.

Quantity of Streamflow

Fire-prone brushland in California and Arizona can be a source of increased streamflow. For example, burning the Fish Creek Watershed in southern California killed almost all of the chaparral, and annual streamflow increased by 2.5 inches the first year after the fire. The increase declined to 0.7 inch by the sixth year, for an average increase of 29 percent for the 6-year period (Hoyt and Troxell 1934). In the Santa Ynez watershed, however, where sediment was eliminated from the total volume of water and sediment, a major fire did not increase total annual flow (Anderson 1955). The burning of a woodland-brush experimental watershed in Arizona sharply increased water yield: over a 36-month period before the fire, accumulated precipitation of 70 inches had produced 3 inches of flow; in 21 months after the fire, 50 inches of precipitation produced 16 inches of flow (Price 1962).

The Tillamook Burn in 1933 in Oregon (partly reburned in 1939 and 1945) increased the total annual water yield of the Trask and Wilson River watersheds (143 and 159 mi^2, respectively) by 9 percent (8 inches) and July-through-September flow by 16 to 20 percent (0.5 to 0.7 inch) for the first 16 years after the 1933 fire (Anderson 1975b).

In 1970 fire killed virtually 100 percent of the surface vegetation on the Entiat Experimental Forest in north-central Washington. Helvey (1972) reported increases in streamflow the first year after the fire that averaged 3.5 inches for three watersheds of about 2 mi^2 each; increases came mostly during spring snowmelt and during the summer months. Debris flow was not measured, but more than 3,000 yd^3 mi^2 was deposited at the mouths of the watershed; this included some boulders as large as 6 ft in diameter (Helvey 1973). Stream chemistry was only moderately affected. Nitrate-nitrogen was increased by a factor of eight, but averaged only 0.04 p/m, whereas cations actually decreased because of dilution by the increased streamflow (Tiedemann 1973).

Peak Flows

The Tillamook Burn also increased annual peak flows from the Trask and Wilson River watersheds. Their annual peak discharge increased about 45 percent the first year after the burn, compared to the adjacent slightly burned Siletz watershed (200 square miles in area). The increase declined to 10 percent by the seventh and eighth years after the burn with no apparent increase thereafter (Anderson 1976b).

A crown fire on the 318-acre South Fork watershed in Arizona killed all but a few of the pine and Douglas-fir trees and consumed litter and ground vegetation. Predicted peaks for an unburned condition and actual peaks after the burn for the four highest flows during the first summer were:

Predicted	Actual
ft^3/s	*ft^3/s*
8	78
2	19
3	16
1	21

Peak flows increased 5 to 15 times, and they continued high through the second summer. Winter peaks did not exceed preburn height (Rich 1962).

Snowmelt flood peaks may be increased by burning the shade-producing trees. We have already noted that burning over half of a watershed on the east side of the Cascade and Blue Mountains areas in Oregon and Washington may increase peaks by about 11 percent (Anderson and Hobba 1959). Both deliberate broadcast burning and frequent wildfire in logged-over areas may have contributed to the

increases from rain-on-snow floods reported. In Idaho, after 18 percent of the Clearwater drainage was burned in 1919, spring flood peaks were 11 percent greater and the average peak flow came 14 days earlier. The Columbia River flood in the spring of 1948 may have been due partly to the large areas of burned-over forest in the headwaters. At the time 31 National Forests occupied about one-third of the basin; more than 5 million acres of them had burned, 11 percent of their total area; many of these lands had recently burned over two or three times (U.S. Dep. Agric., For. Serv. 1950).

The classic test of the effect of burning on snowmelt peak discharges was conducted at Wagon Wheel Gap in Colorado some 50 years ago. There the forest cover was cut and burned on one watershed and left untouched in a paired basin. Peak flows from the treated basin decreased by as much as 50 percent the first two years after the treatment, and were lessened each year by the recovering vegetation until by the seventh or eighth year there was little difference in the peaks from the burned and untreated watersheds (Bailey 1948).

Prescribed burning has been common practice in the Atlantic Coastal Plain for many years. It is applied to reduce brownspot infection of longleaf pine seedlings, competition from hardwoods, or fire hazard. Burning may be repeated every 3 to 10 years. There has been no evidence that this practice results in any great increase in peak flows.

A substantial reduction in the area burned by wildfires has diminished the hydrologic impact of fire. From 1931 until 1936, an average of 42 million acres of forest land burned annually; from 1961 to 1966, the average was one-tenth as much, 4.3 million acres (U.S. Dep. Agric., For. Serv. 1967a), or about 0.4 percent of the total forest area.

Summary

The effects of fire on forest-produced water differ. Light, surface prescribed burns or wildfires have little impact. Wildfire that consumes the forest floor and kills the trees and other vegetation over a large area has major impact on stormflows, erosion, sedimentation, and the quantity of streamflow. Duration of effects is strongly influenced by the rate of revegetation. For the country as a whole, the current level of fire protection has greatly reduced the hydrologic importance of fire from what it was several decades ago. Where severe, widespread wildfire still occurs, as in some areas of the West, fire is still a serious threat to watersheds.

Grazing

Grazing is an annual harvest. Whether its effects become cumulative and reach hydrologic significance depends upon the intensity of grazing, the season of use, and the sensitivity of the land. The most recent survey of the extent and importance of forest grazing was made by the U.S. Forest Service (U.S. Dep. Agric., For. Serv., For.-Range Task Force 1972). This survey estimated that in 1970 about half (85 million acres) of the western forest, and about four-tenths (161 million acres) of the eastern forest were grazed. This study reported exploitative grazing (as opposed to acceptable management) on less than 4 percent (3 million acres) of the area grazed in the western forest, and on 45 percent (72 million acres) of the area grazed in the eastern forest. In Colorado Basin, reduced livestock numbers, improved range management, and erosion control have effectively reduced sedimentation; Hadley (1974) attributed the 50-percent reduction of suspended sediment load carried by the Colorado River to such management.

The grazing of forested watersheds has been the subject of much heated controversy for many years. Some quantitative effects on hydrologic processes have been reported.

Interception and Evapotranspiration

The consumption of foliage by animals in the forest is rarely severe enough to reduce interception significantly or to curtail evapotranspiration; grazing of ordinary pasture land may have greater effect on these processes. Continued heavy grazing can eventually kill or reduce the vigor of trees; either effect will decrease both interception and evapotranspiration.

Infiltration, Overland Flow, Erosion, Sedimentation, and Peak Flow

Woodland grazing may sharply reduce infiltration and increase overland flow by soil compaction. Stoeckeler (1959) measured the following

infiltration capacities in ungrazed and grazed oak and conifer stands in Wisconsin:

	Infiltration capacity (in/h)
Cover:	
Ungrazed native oak	7.46
Grazed native oak	0.05
Ungrazed Scotch pine	11.02
Grazed Scotch pine	1.25

The effect of grazing on infiltration may be much less under other conditions. In some western conifer types, grazing is localized in forest openings and meadows; in such areas infiltration capacities may not be affected in any widespread, continuous manner. On the Manitou Experimental Forest, for instance, infiltration rates "were always high" under litter-covered soil beneath a canopy of ponderosa pine; they averaged 22 percent higher than rates under open-grown pine with a grass understory, and 39 percent greater than on grassland (Dortignac and Love 1961). No erosion was apparent under closed canopies that had a ground cover of tree litter. Lower infiltration rates and greater potential for both grazing and erosion were usual in open forest with a ground cover of herbaceous vegetation and pine litter, and in open glassland parks that supported herbaceous vegetation.

About 8-1/2 percent of the rainfall in eight intense storms appeared as overland flow on a grazed watershed near LaCrosse, Wisconsin. Overland flow occurred only twice on an ungrazed area, and then in insignificant quantities (Hays and Atkinson 1939). A later study at the Coulee Experimental Forest, also near LaCross, showed that only 3 percent of the precipitation from five major storms appeared as overland flow from a heavily grazed woodland. Ungrazed forested watersheds produced no measurable amounts. Peak flow from the grazed area was 0.12 inch per hour or 77 $ft^3/s/mi^2$. Maximum sediment concentrations were 55,900 p/m from the grazed, and 100 p/m from the ungrazed area (Sartz 1976). Another grazed hardwood watershed in Wisconsin lost soil at the rate of 0.1 ton per acre per year, perhaps four times the rate from ungrazed woodland but considerably less than from cropland (Hays and others 1949).

In a more intensive study at Coweeta a 145-acre forested watershed was grazed from May to September for 9 years by an average of six head of cattle. By the end of the first growing season, practically all herbaceous forage and much of the hardwood understory had been consumed, and supplementary feeding was necessary. For a number of years there was little apparent effect on runoff, but by the end of the eighth grazing season, overland flow moved directly into the stream and the frequency and magnitude of peak flows increased immediately and sharply. Before grazing, 2 inches of rainfall (between beginning of flow and peak flow) produced a discharge of about 18 $ft^3/s/mi^2$; after 9 years of grazing the peak was 32 $ft^3/s/mi^2$. Comparable values were 32 and 120 $ft^3/s/mi^2$ for a 4-inch rainfall (Johnson 1952). This grazing treatment hardly affected sediment yield until overland flow finally made its way to the channel in the ninth year of grazing. Shortly thereafter the maximum turbidity in one storm was 108 p/m as compared to 30 p/m from an adjacent ungrazed forested watershed (Johnson 1952). Hursh (1951) attributed to the delay to the accumulation of forest-litter plugs along natural drainage lines; eventually the surface water increased enough to carry away the plugs and develop uninterrupted channels to the main stream.

Dissmeyer (1976) reported that overgrazing in a large river basin in the South caused 92 percent of the estimated accelerated erosion. In the Boise River Basin in Idaho, Rennar (1936) reported that in timber types overgrazing had been responsible for much of the watershed erosion damage.

Summary

Properly managed forest grazing has little adverse effect on surface hydrology or erosion. Overgrazing reduces infiltration and increases overland flow. Voluminous evidence shows that overgrazing increases erosion greatly. Unless it is heavy enough to eliminate much of the forest, grazing has only slight effect on the quantity of streamflow; it can have much greater effects on stormflow volumes and peaks, erosion, and water quality.

Forest-Land Disposal of Waste

The disposal of municipal and industrial wastes may someday be an important use of forest land (Sopper and Kardos 1973), and, depending upon

circumstances or emphasis, the fertilizing of timber crops with wastes may become an accepted forest practice (Gagnon 1973). The areas of forest land used for disposal of waste can satisfy an important need, especially for disposal of sewage from rural communities, even though such use will require only a very small proportion of all forest land. Waste disposal can have significant hydrologic consequences. Use of wastes on the land, under careful control and management, can (1) dispose of the waste, (2) renovate and recycle water, (3) recycle nutrients to increase forest or understory vegetation production, and (4) in some areas serve to create "green belts" for forest fire hazard reduction.

Seabrook Farms pioneered sprinkler irrigation of woodland in the sandy coastal plain of New Jersey in 1949 (Thornthwaite 1951). They discovered early the advantages of using woodland for waste disposal: with an open-field spray, 2 inches of water a day saturated the soil to plow depth and started overland flow; in contrast, when more than 150 inches of water was applied over a 10-day period to a wooded area only 400 feet away, there was no noticeable saturation. Although about 400 to 600 inches of water was applied annually for 19 years, there has been no overland flow. The trees did not survive, but the protective forest floor, augmented by organic debris in the waste water, maintained a high infiltration rate.

In areas where infiltration capacity is low, polluted water has been purified by slow overland flow downhill through forest litter, humus, and ground vegetation. Suspended and dissolved solids are filtered out and converted into humus (Mather and Parmelee 1963).

Effluent from sewage treatment has been successfully sprayed in woodland at the Pennsylvania State University at intensities of 1 to 4 inches depth per week. Water samples collected at the 12-inch soil depth under a red pine plantation showed a 95- to 98-percent reduction in concentration of alkyl benzene sulfonate, a constituent of detergents, and reductions of 68 to 88 percent in nitrate N, organic N, K, Ca, and Mg. The average concentrations of all constituents in the percolate at 12 inches were considerably less than the allowable limits set for drinking water by the U.S. Public Health Service. With a 2-inch weekly irrigation rate from April 8 to November 18, the total weight of constituents applied was equivalent to 2,500 pound per acre of 10-10-10 (NPK) fertilizer (Parizek and others 1967). After nine years of irrigation with treated municipal wastes, no detrimental effects on the forest soil were observed (Richenderfer and others 1975).

Sprinkler systems are now employed extensively in disposal of waste water. By 1957, 250 systems were operated by food processing plants and 18 operated by pulp and paper mills. In 1972, 75 installations in Pennsylvania were spraying municipal wastewater on the land and another 10 to 15 were in planning and design stages (Rhindress 1973).

Waste water and sludge may prove to be useful in reclaiming surface mines (Lejcher and Kunkle 1973). Results of recent tests (Sopper 1975) indicate the revegetation of anthracite coal refuse is possible through the application of treated municipal wastewater and liquid digested sludge. The feasibility of using wastewater to irrigate greenbelts for the reduction of wildfire hazard in California chaparral is being studied (Youngner and others 1973). Irrigation at rates of 1.75 in/week or more maintained moisture content of Ceanothus at levels above 70 percent, where they are not readily flammable.

Much research and development must be completed before the application of wastes to forest land can become widespread or routine. Evans (1973) has suggested 19 research needs; these include economic and social consideration; techniques for handling waste materials; pollution effects on land, groundwater, and streams; effects on animal and plant populations, including crops; infiltration and storage capacities of different soils; cold weather problems; and the need for better systems for monitoring soil and water and adequate standards and guidelines for resultant water quality.

Insects, Diseases, and Weather

A tree killed by insects, disease, or windthrow affects the hydrologic cycle much the same as if it had been cut down; interception and evapotranspiration are reduced or stopped but infiltration usually is not affected. The hydrologic changes differ in detail, and, of course, there is none of the machine-caused site disturbance that usually accompanies timber harvesting.

Insects kill more trees than any other agent; weather (wind, ice and snow, lightning, and drought), and disease kill markedly fewer trees.

The estimated mortality for 1952 was (U.S. Dep. Agric., For. Serv., 1958):

	Growing stock	Live sawtimber
	Million ft³	*Million fbm*
Cause:		
Insects	1,000	5,041
Weather	843	3,387
Disease	773	2,242
	2,616	10,670

A reassessment in 1970 (U.S. Dep. Agric., For. Serv., 1975) was that natural mortality of sawtimber amounted to 15.3 billion board feet annually. If confined to one area, these losses would be equivalent to more than 2 million acres of forest destroyed, and their effect on streamflow would be enormous, as indicated by the individual effects of fire, insects, and blowdown on streamflow amounts and floods.

These damages are scattered throughout the forest land of the country. Mortality in any given affected area is usually caused by a single disease or is confined to a single insect-ridden species, and not all individuals of that species succumb. These conditions modify the impact so that it probably is comparable to or less than the total effect from selection cuttings. This would be true particularly for mixed hardwood stands in the East or mixed conifer stands in the West. Although chestnut blight reduced the production capacity of the hardwood forest north of Maryland by 15 to 50 percent (Boyce 1938), it occurred in mixed stands and was a progressive disease, requiring 1 to 10 years to kill a tree. Streamflow would be barely affected if surrounding trees continued their growth and maintained evapotranspiration rates. Sometimes the effect of damage caused by a single insect species or disease can be singled out and measured, as it was when beetles killed most of the spruce and pine on the 762-square-mile White River drainage in Colorado. Love's analysis (1955) indicated an annual increase in streamflow of about 2 inches in the 1947-51 period following the kill. Total increase in two large river basins for the 25-year period 1941 through 1965 was 22 and 14 percent, or 37 and 30 inches (Bethlahmy 1974). Peak flows were 27 percent higher in the west-flowing White River, but only 4 percent higher in the north-flowing Yampa River.

Catastrophic winds, massive earthslides, and snow avalanches that fell trees over large areas may have greater effects on water than attacks by insects, especially the effects on water quality caused by erosion and sedimentation. The 1938 hurricane in New England destroyed about half the merchantable timber in a swath 80 miles wide extending from Rhode Island and eastern Connecticut to the White Mountains (Barrett 1962). That storm doubtless increased water yield (Patric 1974). Eschner and Satterlund (1966) showed how extensive blowdown in the Adirondacks from a storm in 1950 interrupted a 39-year trend in which the annual water yield from a protected watershed had gradually declined by about 7.7 inches. The blowdown and continuing mortality of storm-weakened trees during the next several years increased water yield to near the original level.

The effects on erosion and erosion-induced turbidity of streamflow are generally minimal; water temperature may be locally affected, and water chemistry may be altered temporarily by leaf fall and accumulation of debris in channels.

The total effect of forest damage by insects, diseases, and weather is usually incorporated into what we accept as normal variability of streamflow.

Minimum-Treatment Management

In land-use planning, the point is frequently made that one possible alternative is to apply no management at all. This practice of leaving lands in their natural state is being applied to more than 11 million acres of officially designated Wilderness Areas, more than 4 million acres of Primitive Area managed as wild lands, and to many other areas. What are the effects on water of such minimum-treatment management?

If complete protection were possible, the trend in forest succession would be toward the climax type, which probably occupies the site more completely than any other. Under this condition, on-site use of water would be at or near the maximum, and erosion and sedimentation would be at a low level in most areas.

Even though protected from disturbance by man, the forest cover may be partly or completely destroyed by fire, insects, or wind, and the water regime may be affected in ways that have already been discussed. The effects of fire and insect attack may be greater than in the managed forest because of the absence of directed prevention and control measures, planting, or other activity for site rehabilitation.

III - SPECIAL PROBLEMS

Unusual conditions in some areas in the United States present special forest-water problems. Though the hydrologic processes already discussed apply in these situations too, we believe special attention to them is merited. The following four situational problems deserve brief special attention:

1. Southern California and Arizona chaparral — an extreme fire-flood-erosion situation
2. Wetland Forests — extreme water abundance
3. Phreatophytes — extreme water use
4. Surface Mining — extreme site disturbance

Southern California and Arizona Chaparral

Of the 759 million acres of forest land in the United States, about one-third is classed as noncommercial because it does not yield wood products. About 101 million acres of this land is in the West. Most of this forest has the same relation to floods, erosion, and sedimentation as the commercial forest does, but about 16 million acres of it behave quite differently. Forests on this land burn readily and completely and thereby set the stage for disastrous floods that usually produce huge volumes of sediment. This is the chaparral area of southern California and Arizona, the country's most inflammable forest and, per unit area, the greatest source of forest-flood damage. In some areas, even unburned chaparral cannot stabilize the soil that supports it. These conditions also exist in varying degrees along the central coast of California and in a belt around the great valleys.

Of the two areas, California's chaparral presents the greater problem. Its 17 million acres of chaparral and associated types have a Mediterranean climate—dry, hot summers and mild, wet winters. Annual precipitation averages about 27 inches but ranges from 12 to 48 inches. Nearly three-fourths of the rain comes during December through March; there is almost none during the summer. Some of the highest rainfall intensities and amounts in the United States have been recorded in this area: 1.02 inches in 1 minute, 11 inches in 7.3 hours, 26 inches in 24 hours, and 43 inches in 3 days (Anderson 1964).

Much of the problem of the chaparral area is caused by its location. Chaparral occupies roughly 70 percent of the mountain ranges fronting the southern third of California's coast. Below it are 300 square miles of valuable properties: homes, orchards, towns, cities, highways, railroads, and industries.

Flood damage can be immense. In the 1938 flood in the Los Angeles area, 87 lives were lost, and property damage was estimated at $79 million. Potential average annual damage there had been estimated at $34 million (U.S. Senate Sel. Comm. Natl. Water Resour. 1960a). The Flood Control Acts of 1936 and 1945 authorized federal flood control expenditures totalling more than $400 million (Hoyt and Langbein 1955). By 1969, about $1 billion had been spent on flood control structures in the Los Angeles area (Wood 1970). Damage following fires and expenditures for flood control attest to serious and closely related problems of fire and flood control.

Fire-Flood-Erosion

Fires followed by the January-February storms in 1969 were responsible for 47 flood deaths (Calif. Dep. Water Resources 1970). Rice and Foggin (1971) and Scott (1971) described the sedimentation consequences of the storm. More than 200,000 cubic yards per square mile of watershed was measured in individual debris basins (Scott 1971).

Colman (1953a) described three other fire-flood-erosion sequences. On New Year's Day in 1934, less than 2 months after fire burned 7 square miles of chaparral in the mountains above the cities of Montrose and La Cresenta, a severe storm struck. The flood that followed killed 30 persons, devastated several towns, and caused $5 million damage; unburned watersheds nearby produced only normally high streamflow.

In July 1945 an airplane crashed into the chaparral of the upper Santa Ana River watershed, and started a 4,000-acre fire. Although this burn covered only 1/25th of the watershed, thunderstorms that autumn caused mud and rock flows that interrupted the operation of three hydroelectric plants and disrupted irrigation schedules on 10,000 acres of citrus orchards.

In 1950, the fire-flood-erosion sequence was most convincingly demonstrated. A fire on July 4 in the hills 4 miles north of Yucaipa, California burned about 630 acres of chaparral. Two days later a severe thunderstorm struck the burn and areas surrounding it; mud and boulders poured from the burned area in quantities that blocked

roads and incurred several thousands dollars' worth of damage. There were no flood flows or erosion on adjacent unburned drainages (Colman 1953b).

Such damaging fire-flood sequences had led to record expenditures for fire control. The average annual per-acre costs in the chaparral zone are several times the national average (Davis 1959).

Streamflow records from experimental watersheds in the San Dimas Experimental Forest before and after fires give some indication of fire's effect. After a fire in 1938, two storms from an unburned watershed produced peaks of 7 and 17 $ft^3/s/mi^2$; a watershed only 3 percent burned had peaks of 12 and 20 $ft^3/s/mi^2$; and one 26-percent burned had peaks of 26 and 55 $ft^3/s/mi^2$. After the 1953 burn, a heavy storm on an unburned watershed caused a peak of 5 $ft^3/s/mi^2$; on one 3-percent burned, a peak of 20 $ft^3/s/mi^2$; and on one 32-percent burned, a peak of 429 $ft^3/s/mi^2$. With wet soil conditions and smaller storms, peaks from burned watersheds were 1.2 to 15.6 times greater than peaks had been when the watersheds were unburned (U.S. Dep. Agric., For. Serv., San Dimas Exp. For. 1954).

The 1960 fire at San Dimas produced even greater differences. For two of the larger watersheds, 740 and 875 acres, peak flows from a 4-inch storm before the fire were 0.76 and 4.4 $ft^3/s/mi^2$, respectively; a similar storm after the fire gave comparable peaks of 660 and 880 $ft^3/s/mi^2$ (Krammes and Rice 1963). Statistical relations between flood peaks and sedimentation and forest fires, and the recovery of vegetation after fires, have provided a basis for intensified fire protection (Anderson 1949b).

Tremendous discharges from freshly burned areas may be due partly to fire-derived nonwettable layers of soil. These layers are formed when large soil temperature gradients cause vapor and gases containing hydrophobic substances to move downward from the surface organic matter into the surface soil. There they condense on soil particles and inhibit infiltration. The depth and thickness of the water repellent layer depend on the intensity of the fire and the amount of vegetation and litter consumed (DeBano and Rice 1973). Soil texture also seems to be a factor; clay soils are less susceptible than sandy soils (DeBano 1969). Similar repellency has been reported for soils under both natural and burned chaparral in Arizona (Scholl 1975). Small-scale research tests indicate that chemical wetting agents may be useful in reducing overland flow and erosion from nonwettable soils, but recommendations cannot be made yet for general application (Krammes and DeBano 1967). A large-scale test failed to reduce overland flow and erosion during the 1969 flood (Rice and Osborn 1970).

Water repellency of soils developed by fire may prove an advantage in reforestation of burns. DeBano and Rice (1973) have suggested that if stock is planted in contour furrows, the extra runoff from the inter-furrow repellent areas will be trapped in the furrows and provide moisture to nurture the new seedlings. It would seem also that alternate furrows for trees and dense contour seeding, such as rows of barley or mustard, would accomplish both immediate erosion control and reforestation.

Erosion Without Fire

Along the Los Angeles front of the San Gabriel Mountains in southern California, watersheds long unburned steadily contribute sediment to stream channels. On south-facing slopes of 90 percent in the Los Angeles River watershed, that have a cover density of 65 percent, debris moves into the channel at an average annual rate of 3.56 tons *per acre*. A little more than half of this is deposited during the dry season; many of the slopes lie at angles steeper than the natural repose for dry material. "A breeze that shook the brush was enough to start a minor slide. . ." During the rainy season most deposition occurred after soil-moisture storage opportunity was satisfied. Debris movements from north-facing slopes of 70 percent and from north- and south-facing slopes of 55 to 60 percent averaged from 0.2 to 0.72 tons per acre per year (Anderson and others 1959).

Highly erodible road slopes in southern California also pose problems. Erosion from road fills has averaged from 6 to 10 times that from adjacent nonroad areas (Anderson and Wallis 1965). Special erosion-prevention procedures must be used (Kraebel 1936). On the Angeles National Forest they include reducing volumes of cuts and fills by using retaining walls and cribbing, reducing design speeds to meet minimum traffic needs, fitting road alignment to topography, keeping road gradients to a minimum, and contour-trenching, staking, and seeding of fill slopes (Usher 1961).

The methods for stabilizing road-fill suggested by Kraebel (1936) were used on the road to the Palomar Mountain Observatory in southern California (Juhren 1949). The road-fill treatments consisted of contour wattling (bundles of brush 6 to 7 feet long and 4 to 6 inches in diameter placed end to end in contour trenches) together with seeding of barley or ryegrass, using wheat straw between rows, and planting willows, mulefat, trees, and shrubs. In the 1938 flood, erosion from unprotected slopes was as much as 680 cubic yards per acre, equivalent to 5 inches' depth over the area. The only fills that did not erode were those treated. Since many of these improved methods also reduce costs of road maintenance, there is hope for prevention of major increases in sediment discharge from large road construction projects.

Erosion After Fire

Sedimentation accounts for much of the fire-flood-erosion problem in the chaparral of southern California. During the summer following the Woodwardia fire in October 1959, dry creep from steep slopes increased by 4 to 17 times. Erosion directly related to the fire ranged from 2.2 to 24.7 tons per acre the first year; south-facing slopes yielded the most debris—10 times the preburn rate. About 89 percent of the eroded material came from surface sloughing during the dry season (Krammes 1960).

Increases in rainfall erosion were even greater in another area. After the January 1954 storm on the December 1953 burn at the San Dimas Experimental Forest, an average of more than 0.6 inch of ash, soil, gravel, and decomposed rock was removed from side slopes by sheet and rill erosion. In addition, the material from channel erosion gave an estimated erosion rate of 55,500 yd^3/mi^2 of burned area. The normal erosion rate for that drainage is about 2,000 yd^3/mi^2 per year (U.S. Dep. Agric., For. Serv., San Dimas Exp. For. 1954). These values are not exceptional for this part of the country. Forty-one watersheds in southern California, from 1 to 1,465 square miles in area, produced annual averages of 600 to 9,770 cubic yards of sedimentation per square mile. After one-fourth of the watershed was burned, estimated production from a 100-year flood was 9,900 to 113,000 cubic yards (Anderson 1949b). Maximum yearly sedimentation of 71 debris basins guarding the San Gabriel Mountain front has ranged from 3,500 to more than 200,000 yd^3/mi^2 (Los Angeles County 1970).

Control and Rehabilitation

Flood and erosion control require prevention or control of wildfire. Land managers agree that this requires construction of firebreaks and some managers recommend reduction of fuel by converting chaparral covered land to grassland wherever feasible. This conversion, however, may reduce the opportunity for soil-water storage. Conversion from chaparral to grass cover at San Dimas increased the average daily evapotranspiration rates during the rainy season from 0.048 to 0.059 inch, an average annual increase of about 2 inches. Most of it occurred from January to April when scrub oak growth was slow and annual grass growth relatively rapid. Evapotranspiration from grass practically ceased when the grass matured in early summer, having used all available water to a depth of 2 1/2 feet and created some water storage opportunity to depths of about 7 feet. During summer evapotranspiration losses were far greater from the chaparral (0.073 compared to 0.034 inches per day) and continued until all available moisture in the 12-foot soil depth had been utilized (Rowe and Reimann 1961). The soil-water storage opportunity on deep soils under chaparral is almost always more effective for flood control. During the January to April rainy season, the somewhat greater soil-water deficits built up by the greater evapotranspiration under grass are quickly satisfied in any flood-producing storm. The soil slippage problem in steep grassland is discussed later in this section.

Burned-over watersheds have such high damage potential that they must be rehabilitated immediately. Annual ryegrass, broadcast seeded, can provide a quick ground cover that persists for a few years but does little to moderate damages from peak flows. Wheatgrasses (long-lived, drought-tolerant bunchgrasses) have performed well in tests. They mature somewhat later in the spring or summer than many other grasses —an important consideration in planting for fire control and for a fuel-break cover (Bentley 1967).

The treatments following the 1960 fire at the San Dimas Experimental Forest are a good example of erosion control (Rice and others 1965). Tested were broadcast seeding annual and perennial grasses, bulldozing wide contour trenches (Bailey and Croft 1937), building check

dams in channels, and planting barley in contour furrows. The total debris produced during the first year after each of four treatments was:

Treatment:	*Yd³ acre*
None	29
Contour trenches	14
Channel check dams	17
Contour planting	10

The check dams filled quickly to their design capacity during the first two storms. Contour trenches, although large, could not be spaced closely enough to provide adequate storage for runoff volumes from large storms. Planting barley on the contour was the most successful treatment: seeded at the rate of 150 pounds per acre and fertilized, it prevented appreciable overland flow, but the treatment deteriorated rapidly 2 years after sowing (Krammes and Rice 1963). Standard rates of grass seeding, because of steep slopes and surface instability, accomplished little for it did not produce a total vegetative cover significantly greater than that on unseeded controls. A high-density (20 lbs/acre) sowing of a mixture of annual grasses did reduce erosion by 16 percent. The average cost of helicopter sowing on large areas is about $1 per acre plus cost of seed (about $4 per acre for high-density annual mixed and $13 for perennial). The cost of barley in contour rows is about $140 per acre. This measure must obviously be restricted to critical erosion areas (Corbett and Green 1965).

Soil slippage in brushland converted to grassland following a forest fire had produced 3 to 7 times as much erosion by two large storms as occurred in naturally recovering brushland (Rice and Foggin 1971).

Removing flood debris and seeding of watersheds as an erosion control measure following a fire can cost more than fire suppression. For the 1960 fire at San Dimas, the fire suppression cost (Federal only) was $800,000, whereas cleanup and erosion control cost $917,000. In the first 2 years after the fire, debris production amounted to 24,000 cubic yards per square mile. During the same period, 33 unburned watersheds in the surrounding San Gabriel Mountains produced 6,000 cubic yards per square mile, while 16 partially or completely burned ones produced 40,000 cubic yards per square mile (Rice 1963).

To prevent erosion from unburned watersheds in southern California, various reinforcements of existing vegetation are recommended. To reduce sliding from upper slopes, species should be found that will convert the original single-stemmed vegetation to a multi-stemmed but deep-rooted cover. On slopes that exceed the angle of repose, the soil mantle can be tied to the underlying rock by additional vegetation without reducing the effectiveness of the existing deep-rooted brush. To prevent gullying of colluvial deposits, overland flow should be spread by mechanical means or by planting multi-stemmed vegetation; widely-spaced, single-stemmed vegetation is relatively ineffective (Hellmers and Anderson 1955).

No rehabilitation measure yet devised gives immediate protection comparable to unburned chaparral. Debris basins or other protective devices are often needed to reduce damage after fire.

Arizona Chaparral

Arizona has about 4 million acres of chaparral, varying from dense stands to open, desert-like scrub. Annual precipitation on this area is somewhat less than that on the California chaparral; it ranges from 16 to 25 inches. Most of it comes as winter rainfall; but in contrast to California, summer storms account for about one-third of the total annual precipitation and those storms can cause flooding and erosion.

The Arizona chaparral, like its California counterpart, can be completely consumed by fire. Peak flows and sediment production increase immediately. After an intense fire, one of the 3-Bar Experimental Watersheds produced 40,000 tons of sediment per square mile over a 6-month period; unburned watersheds produced from negligible amounts of sediment over periods of 2 to 3 years to as much as 500 cubic yards of sediment per square mile from two storms of 1 to 2 inches (Glendening 1959). With 70 inches of accumulated precipitation, accumulated sediment was about 200 tons per square mile in the 36 months before the fire; in the next 21 months after the fire, accumulated sediment increased 100-fold to 22,000 tons per square mile with 50 inches of precipitation (Price 1962). Within 3 years after the fire, the severe flooding and sedimentation on the 3-Bar Experimental Watershed was controlled to near prefire levels by the vigorous growth of introduced lovegrasses plus some fifty species of native herbaceous cover (Pase and Ingebo 1965).

Conversion of brush to grass may interrupt the erosion cycle associated with wildfire as well as

produce one-third to 5 inches more streamflow (Hibbert and others 1974). T.C. Brown and others (1974) estimated that it might be economically feasible to convert about 300,000 acres of National Forest land in the Salt-Verde Basin of Arizona to useful species of grass.

Because of the lesser concentration of population below chaparral watersheds of Arizona than in southern California, flood damage from Arizona Chaparral watersheds is less spectacular but still locally important.

Wetland Forests

Wetland forests generally reflect a dominant influence of an abundant supply of water seasonally or otherwise (Bay and Klawitter 1963). They cover nearly 37 million acres in the southern and southeastern United States, bordering the Atlantic and Gulf coasts and in the lower Mississippi Valley. In the Lake States also, large areas of wetlands are in bogs. Present management there is directed largely to obtain regeneration of forests following harvest (Boelter 1974). Water management is being practiced on more than 2 million acres of wetland forest in the southeastern United States (Klawitter 1972). Although most of this management has increased timber productivity of the land, it may have various hydrologic consequences as well. The primary objective of water management designed to fulfill productivity objectives is to hold sufficient water on some parts of the land to obtain maximum forest growth but in other places to remove surplus water in an orderly manner. Surplus water in headwater bays and wet flat lands is not waste water, for such water is used to recharge swamps in bottom land soils; to maintain water fowl, aquatic, and estuary habitats; and to provide buffer against salt water intrusion. To accomplish these objectives, a water management system must be designed to meet both on-site and the downstream objectives. The design will vary depending on the type of wetland involved. Klawitter (1972) has summarized management objectives and techniques for four types of wetlands: wet flats, bays, swamps and upland ponds, and bottomlands.

Wet Flats

Wet flats are upland sites located on broad, level to nearly level, interstream areas of the lower coastal plain and flatwood section. Most efforts in water management are now concentrated on the 4 million acres of wet flats that support pine. One current procedure is to remove surface water and lower the ground water enough by means of surface ditches to increase the trafficability for heavy equipment and thereby facilitate road construction and timber harvest. For estimating the effects of drainage on flood flows, Klawitter (1972) suggested that the maximum 24-hour average flow rates can be computed by using the Cyprus Creek formula (Stephens and Mills 1965). He applied this formula to southeastern wetland areas, and arrived at a water removal rate of 1 inch in 24 hours (this is equivalent to 27 $ft^3/sec/mi^2$ of drained area).

Bays

Bays, or upland bogs, cover approximately 3 million acres of wet forest land in the coastal plain. Although they can be found throughout the Southeast, they are mostly in eastern North Carolina or in the northern part of the flatwoods section. Coastal plain bays typically produce relatively little timber, water, forage, and wildlife. Because of fertility problems, Ralston (1965) concluded that not enough is known at this time about the hydro-chemical processes of infertile bay soils to recommend suitable measures to improve forest growth. Numerous stumps have been uncovered where roads or ditches are constructed in this wetland type; this indicates that major vegetation changes have taken place in these areas. Trousdell and Hoover (1955) reported that logging caused water levels to rise enough to endanger regeneration and seriously hamper projected future logging operations. Hydrologic consequences of such changes in the vegetation have not been evaluated.

Swamps and Upland Ponds

Swamps occupy the lowest location along the sluggish streams and rivers in the coastal plain and in the broad depressions in the heads of streams. Occasionally, maritime terraces or sand ridges formed by the sea block areas of low-lying land; these terraces form large swamps like the Dismal Swamp in Virginia, and the Okefenokee Swamp in Georgia and Florida. Upland ponds occupy small depressions in bays, wet flats, or piney woods and are managed in conjunction with them. They are frequently as wet as swamps, but

depend on overland flow and seepage from surrounding uplands for their water supply. Swamp vegetation is well adapted to the wet environment: such species as bald cyprus and water tupelo grow best on these sites.

Removal of surface water from swamps can kill older trees and also destroy waterfowl habitat, sanctuaries and escape for deer, and conditions suitable for other wildlife. These values can be enhanced by such methods as installing dikes and control structures at well chosen locations to control the water levels in swamps. Hydrologic consequences of such management have been little studied; however, the characteristics of increased pondage and retention of flood waters would indicate a reduction of flood runoff.

Bottomlands

Bottomlands provide the extra channel capacity required to carry stormflow to the sea. Small streams seldom support a width of more than a few hundred feet, whereas major rivers are frequently separated from adjacent uplands by several miles of bottomlands. Productivity in such bottomlands is high for both timber and wildlife because of the excellent inherent fertility and abundance of moisture in bottomland forest. Uncontrolled drainage adversely affects stand composition, tree growth, and regenerative potential of these lands. Consequently, current water management consists of a kind of flood irrigation—increasing the water available for plant growth by impoundment—construction of low dikes and dams in flats and shallow drainageways (Schlaudt 1962, Broadfoot 1964, 1967). Again, the hydrologic consequences have not been well studied; however, some additional use of water would be expected and some detention benefits of the temporary pondage would reduce flood peaks and prolong water yields in downstream areas. Shallow-water impoundments in bottomlands may attract waterfowl and hence have benefits additional to those of growth and water control. Klawitter (1972) concluded that water management is a means of improving the productivity of millions of acres of wetland forest for wildlife, timber, forage, and water in the southeastern United States. Hydrologic consequences and opportunities associated with the detailed management techniques and wetland conditions need further study.

Phreatophytes

Phreatophytes are trees and shrubs that thrust their roots down to the groundwater under and adjacent to stream channels. Most phreatophytes grow below the forest zone, in desert or plains rather than in a forest environment; for that reason, discussion here is brief. According to one estimate, phreatophytes consume about 25 million acre-feet of water per year in arid and semiarid areas of the West; this is equivalent to about twice the average annual flow of the Colorado River at Lees Ferry, Arizona (Babcock 1968).

On a per-acre basis, phreatophytes consume an estimated 4 to 9 acre-feet of water. How much of this can be "saved" by cutting saltceders, arrowweed, and cottonwood (three chief water users) and how much of the "saving" can be converted to more beneficial use are questions research has not yet answered. In some places this vegetation has enhanced values for recreation and wildlife that have exceeded the estimated value of water that would be saved by removing it.

Horton and Campbell (1974) have summarized some of the possibilities and limitations for management of phreatophytes, and Horton (1973) published a comprehensive abstract bibliography of research related to management of phreatophytes and other riparian vegetation.

Robinson (1967) reported that annual savings in areas of dense growth may amount to 2 to 3 feet of water. The depth of the water table may determine the ultimate management of these areas. If the depth is 4 feet or less, cleared areas can be sown to grass. If it is more than 4 feet, replacement of vegetation is more difficult; farming with irrigation presents no problem, but elsewhere the cleared areas invite wind erosion (Horton 1966).

Rowe reported (1963) that during the first dry season following clearing of streamside vegetation along a channel in the San Dimas Experimental Forest, the clearing saved the equivalent of 14 inches depth of water per acre cleared (Rowe 1963); moreover, streamflow increased chiefly in summer and at the beginning of the soil-wetting period in subsequent seasons, when flow usually was lowest and water was most needed.

In the largest phreatophyte control program yet attempted, one area of 5,300 acres in the Rio Grande Valley was cleared of vegetation (principally saltcedar and mesquite); this saved an estimated 14,000 acre-feet of water annually. In current

projects, thousands of acres are being cleared in New Mexico, Arizona, and Texas.

Until recently phreatophytes were almost universally regarded merely as wasters of water. Now their place in the environment is coming to be recognized, and multiple-use planners are assessing the benefits of phreatophytes to fish, wildlife, and aesthetics. For example, Bristow (1968) has estimated that the hunting of whitewing doves on 1 acre of phreatophytes in Arizona can add about $880 per year to the economy of the state.

Surface Mining

Surface mining, chiefly of coal, has increased steadily since Word War II. Until 1965 an estimated 3.2 million acres of land, much of it forest, had been disturbed by surface mining in the United States; an estimated 150,000 acres was disturbed in 1964, and the rate has been increasing since then (U.S. Dep. Inter. 1967). In the West alone more than 21 million acres of commercial quality coal and phosphate areas may be subject to surface mining (Copeland and Packer 1972).

Cutting the forest and disturbing the soil in surface mining has much the same effect on water as other activities already described, but the disturbance is greater—truly extreme—and the effects greater. Surface mining sometimes exposes types of rock that have a high potential for polluting the water in streams and impoundments with acid and other deleterious chemicals.

Reclamation of surface-mined areas has proved extremely difficult. For this reason surface mining has been and continues to be the subject of much controversy and legislation. Reclamation involves both engineering—including the proper placement and grading of spoils, provisions for drainage, and sometimes impoundments for trapping sediment—and establishing vegetation. It is being increasingly recognized that, for successful reclamation, the mining operation must be planned and conducted from the beginning with adequate consideration for reclamation requirements.

Mined areas are often difficult to plant or replant. Fertilizing (usually with nitrogen and phosphorous), liming, and irrigation may be required. Sometimes followup treatments are necessary after initial establishment to insure adequate continued growth.

Where forested areas are mined, the reclamation objective is usually to reestablish forest cover. Forestry has a dual role: (a) establishing trees and shrubs to stabilize the site, control erosion, and improve aesthetics, and (b) returning the land to productive use: timber growing, game habitat, recreational use, or some combination of these uses.

Reclamation research was begun in the 1930's by the U.S. Forest Service in the Central States (Limstrom 1960); now several universities and other Federal and State agencies are also studying the problem. Practical methods for planting trees in the East and Midwest have been developed and guides have been published (Paton and others 1970, Davis 1971).

Increasing attention has been given recently to research on the formidable hydrologic problems that follow strip mining (Curtis 1971a, 1971b, 1972a, 1972b). Maximum sediment concentrations from three watersheds in Appalachia increased from 150 p/m to 46,400, 26,900, and 9,600 p/m, respectively, after these watersheds were strip mined. Peak flows increased by a factor of 3 to 5 after surface mining. On the other hand, water quality from restored strip mine areas in pinyon-juniper land in Arizona was well within EPA criteria; content of nitrate nitrogen in water was less than from the unmined control watershed (Verma and others 1975).

Most surface mining in the United States has been done in the East, but it is proposed for producing coal and other minerals in many states in the West (Copeland and Packer 1972). Revegetation, with trees or other vegetation, is difficult under the relatively harsh soil and climatic conditions widespread in the West.

A large volume of literature on reclamation is accumulating (Frawley 1971, Hutnik and Davis 1973, Cook and others 1974, Johnston 1975). Specific techniques for reclamation have been developed to overcome problems of lack of nutrition, adverse microclimate, inadequate water, and erosion inhibiting establishment of plants. Water supply for establishment has been provided by using water harvesting techniques of laying impervious strips between plantings with wax or polyethelene or by irrigation (Aldon 1975). Shaping the soil surface so as to trap snow to augment the water supply has been suggested (Tabler 1975). Use of artificial barriers to stabilize the surface on steep or highly erodible slopes has been found effective (Heede 1975). Much testing has been done to identify plants suitable for use at specific sites (Cook and others 1974), including use of legumes to improve fertility (Vogel 1973).

IV - POTENTIALS FOR MANAGEMENT

The potentials for management and the pressures for improved management differ widely nationwide. In 1962 the U.S. Department of Agriculture estimated that more than 220 million acres of forest and other woodland in the continental United States needed better management to improve conservation of both soil and water (U.S. Dep. Agric. 1962). Here we first discuss potentials for management in general terms and then focus upon six separate extensive regions, each of which has its distinctive forest-climate relationship.

Our prime concern here is forest management with respect to water: increasing water yield, enhancing the forest's flood control function, increasing its prevention of erosion, and expanding its protection of water quality. The multiple-use manager must, of course, use data relating to all phases of resource use in developing strategy for effective management of the forest.

For specific local forested areas, such as those that directly supply municipal water systems, watershed management considerations may be paramount. On other forested areas, watershed management may receive relatively less emphasis than management to promote or provide other goods and services; these differing relative emphases result from social as well as resource considerations.

Conflicting Objectives

While acknowledging the importance of forestry in helping to solve problems of water yield, floods, and water quality, we must emphasize that forestry provides no cure-all; some management objectives are hydrologically incompatible with others. No single method of managing forested watersheds can improve all aspects of water yield and control. If we want more water, we may sometimes get it when we do not want it, and we may have to make special provisions to keep that extra water from damaging property. If we want water yield delayed for summer irrigation, the delay may sometimes reduce production of waterpower in winter or spring. The purest water generally comes from the least used forest. The objective of flood control is not compatible with achieving the greatest water yield. In some places the conflict over objectives is critical; in others, trivial.

Forest management for water production and control must be coordinated with other water management practices, such as construction and operation of reservoirs and filter plants, weather modification, and water harvesting.

Financial incentives often are the deciding factor in determining individual land owners' objectives and whether they practice watershed management. In the words of Marion Clawson (1972), "Unless or until some means can be devised whereby forest managers can gain financially from watershed management, very few programs aimed at increasing the supply or improving the quality of water from forested watersheds will be undertaken" —at least on most private lands. However, public opinion and legal restraints are beginning to exert strong influence on water management of forest lands (Meier 1975).

Management for Water Yield

Forests cover about one-third of the conterminous United States and mark the areas of greatest precipitation and streamflow *(fig. 1)*. These 650 million acres of forest receive about one-half of the country's total precipitation and yield about three-quarters of its total streamflow. On a unit area basis, forest land receives about twice as much precipitation annually as other land, 45 inches versus 22. Because it receives more water, the forest consumes more water than other areas, 25 inches versus 19. More of the precipitation becomes streamflow—20 inches, or 44 percent, from the forest; 3 inches, or 15 percent, from other lands (Wooldridge and Gessel 1966). Forest regions of the United States coincide closely with areas where average annual precipitation exceeds 20 inches and average annual streamflow exceeds 5 inches. Forests and streamflow are highly correlated, particularly in the West. In the Columbia-North Pacific, California, Great Basin, and Upper and Lower Colorado Regions, more than 90 percent of the streamflow originates in high altitude watersheds that are largely forested and are predominantly in National Forests (Water Resources Council 1968).

Water shortages occur locally throughout the country but are more serious in the West. For example, in four of the six western forest regions, the Water Resources Research Council (1968) rated water shortage a major problem; in seven of eight regions in the East, it was rated a minor problem.

By the year 2020, the annual demand for water produced in forested regions is expected to increase

by 30 million acre-feet in the East and by 39 million acre-feet in the West, according to projections by the Water Resources Council (1968) for water source regions that contain most of the forest area.

These demands for water may be met in varied ways (National Academy of Sciences 1971). New sources of water may be made available by such familiar techniques as cloud seeding and desalting of saline water; less well developed, such as augmenting fog drip, creation of artificial ice fields, and deliberate snow avalanching, also have possibilities. Part of the demand for more water may be met by conserving existing sources of water. This may be accomplished by vegetation management, reduction of evaporation from soil water and snow surfaces, and by restoration of water quality by reclaiming wastewater. Further, some water can be made more useful by being transported from areas having excess supply to areas of deficit or by using water where it supplements existing supply. Consideration and comparison of the alternatives strongly suggests that the forest may often be a productive and economical source of more water. But since some increases may produce floods, care must be exercised to insure that increases in water yield are useful rather than damaging.

Management for Maximum Water Yield

Research has shown that water yield from forested areas increases as evaporative losses are reduced; therefore, the maximum possible increases from forest cutting are obtainable by some form of clearcutting. First-year increases following clearcutting range from 1 to about 18 area-inches throughout the country. How long the increases in water yield persist depends on the rate of regrowth, which differs widely among regions and vegetation types.

Most of the increases in water yield that have been measured have been on small experimental watersheds surrounded by large forested areas *(table 8)*. In effect, small watersheds are holes cut into the forest canopy. This means that the microclimate on the clearcut areas is not the same as that on fully open areas. The results of clearcutting an area large enough to function as a completely open area have not been completely evaluated. Some large-scale effects appear to be similar to those on the experimental watersheds. The increased runoff from the 300-square-mile Tillamook Burn is like the result of the clearcutting on the H. J. Andrews Experimental Forest. In the East, the decrease in streamflow associated with regrowth on the Sacandaga Watershed is in accord with results at Hubbard Brook. Clearcutting of large areas is unlikely; however, the hydrologic consequences of management of large open areas may be of interest, for some such area may be considered for restoration of the forest.

Water-Yield Increase Resulting from Multiple Use

The possibilities of managing the forest simultaneously for timber, water, wildlife habitat, and other uses have achieved greater importance in recent years following managerial and legislative recognition of the multiple-use potential of forest lands. To some degree we can now have timber harvest, or other use, and more water, too. To some degree we have had both in the past. Although increases in water yield resulting from past forest cutting were usually not evaluated, they must have been substantial. In about 100 years, the area of commercial forest in the United States was reduced from 828 to 484 million acres. Ninety-two percent of this reduction, 316 million acres, was in the East; it cleared 42 percent of the land in 29 states. Now about 2 percent of the total timber is cut annually.

Although we can expect more attention to water in multiple-use management of public lands in both East and West, the withdrawal of lands for wilderness, parks, scenic rivers, and other such special uses will reduce the possibilities for water management as well as timber harvest.

Management for water yield may deserve major emphasis in snowpack zones, for their yields are high, and they have potentials for affecting the amount, timing, and duration of yield. A snowpack zone is any area that receives 60 inches or more of snowfall annually. The snowpack zone is an important source of streamflow in both the Northeast and the West, but the potential for management to increase water yield is much less in the Northeast. These include parts of Maine, Vermont, New Hampshire, New York, northern Michigan, and high elevations in the 11 Western States—a total of about 240 million square miles, most of which is forested. The snowpack zone comprises a little more than one-third of the nation's total forest area. In New England and New York, streamflow in April and May, the prin-

cipal snowmelt months, constitutes 35 to 50 percent of the annual yield (Lull and Pierce 1960). In the Colorado Rockies above 9,000 feet, probably about 90 percent of the annual water yield originates from snow (Goodell 1966). The snowpack zone in California, 12 percent of that state's land area, furnishes an estimated 51 percent of its streamflow (Colman 1955).

Noncommercial timber lands both above and below the commercial forest zone, mostly in the West, can also provide sizable and widely distributed areas suitable for water-yield management. Generally these lands are in regions where annual precipitation exceeds 18 inches. Research has indicated that the National Forests, under multiple-use programs, can produce an increase in water yield of 9 million acre-feet annually (U.S. Dep. Agric., For. Serv. 1967b). This increase is said to be compatible with sustained-yield timber management. About 7 million acre-feet of the total would be derived from the commercial forest, about 1 million from phreatophyte clearing, and the remainder from chaparral and other areas. These estimates are for total potential; considering the time required to start such a program, a more practical estimate of what could be achieved in the next 50 years is 3.7 million acre-feet. New techniques could increase yield and speed up applications of management for increased water yield.

These increases in water yield possible under multiple-use management are attainable by clearcutting in suitably designed patterns, encouraging growth of hardwoods rather than conifers, and prohibiting tree planting in riparian areas. Smaller and shorter-lived increases can sometimes be attained by selection and other timber cutting practices. Only effects on water yield are considered here. However, steadily increasing demands for water, timber, and other forest products will inevitably require emphasis on their simultaneous production. Within any area of management, these uses may well be reconciled by economic analyses like those suggested by Gregory (1955), Black (1963), and Brown and others (1974). The proper combination of timber and water production occurs at the point of greatest possible difference between total cost and total revenue. Restraints designed to prevent undesirable effects on the environment will be increasingly imposed.

Cost of Increasing Water Yield

The costs for increasing water yield under multiple-use management are only a fraction of total costs for maximum yield *(table 11)*; they result from required special cutting practices that restrict the volume harvested and require cutting patterns that may add to logging costs. The estimated cost of $25 per acre-foot for maximum yield is equivalent to 8 cents per 1,000 gallons. The cost of water obtained by increasing forest water-yield is about one-fourth to one-half the cost of that obtained by any other current method except cloud seeding, a method not yet fully researched for its effects over large areas.

Table 11—*Costs of additional water obtained by alternative methods*

Method and location	Cost per acre-foot
	Dollars
(1) Forest management by multiple use:	
Western National Forests	1.44
Commercial forest, United States	0.89 to 3.17
(2) Maximum water yield	
Fernow Exp. Forest, W. Va.	20 to 30
(3) Salt water conversion	
Various locations	80 to 160
(4) Water transmission	
From N. California to New Mexico to Los Angeles	45 to 65
(5) Harvesting water from asphalt basin	
Arizona and New Mexico	80 to 160
(6) Cloud seeding	
California	0.40 to 4

Compiled as follows: (1) U.S. Dep. Agric., Forest Serv. 1967b (estimates by Irvin C. Reigner, Ralph C. Maloney, and E. G. Dunford, Aug. 2, 1969, on file, Forest Serv., U.S. Dep. Agric., Washington, D.C.); (2) Lull and Reinhart 1967; (3) Kohout 1969; (4) Patric 1959; (5) Black and Popkin 1967; (6) Kriege 1969.

In some locations water yield can be substantially increased by forest management designed primarily to produce maximum yields of high quality water. This would cost less than other methods that are sometimes deemed practical. Forest watershed management deserves to be considered as an alternative or an adjunct to other methods. It is more flexible than most alternatives; it can be deferred until the time of maximum need; it can be applied to meet even small local needs; and to some extent it is reversible and can be abandoned without difficulty. The value of yield increases through watershed management may, however, depend on available reservoir storage (Hoover 1969). Forest management may be practiced to increase the effectiveness of water production by cloud seeding.

Leaf (1975a) has estimated, for example, that the combination of converting 40 percent of a forest area in central Colorado into openings 5-to-8 tree heights across, plus augmentation of snowfall by 15 percent (by cloud seeding), would double water yield from the treated area.

Management for Flood Reduction

Floods are among the most damaging of all catastrophies. The Water Resources Council (1968) estimate of potential annual damage (in the absence of protective measures) in the United States was $1.7 billion; by 2020 it will be $5 billion.

Flood damages steadily increase. In 1957, the dollar loss was double that of 1936 despite the expenditure during the 1936-57 period of $4 billion in flood prevention activities. Bernstein (1974) reported that a 1973 appraisal gave an estimated $7 billion having been spent for flood control since 1936; yet annual flood losses are about $1.25 billion and are continuing to increase. Increasing losses have been charged to more frequent flooding, the rise in property values, and the greater occupancy of flood-prone lands.

Forests, which occupy the major area of upland watersheds, are directly associated with flood damage in tributary streams. Estimates of the proportion of total flood damage that is incurred in upland watersheds have ranged from 40 percent (U.S. Senate Sel. Comm. Natl. Water Resour. 1960a) to 56 percent (Ford and others 1955).

Forest-flood relations in the East have been discussed in detail by Lull and Reinhart (1972). Floods resulting from late summer or fall hurricane rains strike the East. The most damaging storms in the Northeast were in 1955 and 1972. There were two hurricanes in 1955; rainfall from Hurricane Connie saturated the soil, priming it for the next week's onslaught of Hurricane Diane, which deposited record rainfall in eastern Pennsylvania, New York, and southern New England. In 1972, Hurricane Agnes became stationary over Pennsylvania. It deposited as much as 18 inches of rainfall during the period of June 20 through June 25, and caused the biggest flood ever recorded on the Susquehanna River (Pennsylvania State University 1972). Hurricane Camille in August 1969, which deposited 28 inches of rain in 8 hours, was most damaging in Virginia (Williams and Guy 1973).

In the East, floods from snowmelt alone are rare, but they occasionally occur. The flood in April 1928 in the deep snow country of the western Adirondacks was caused solely by the delayed thaw of a heavy snow cover (Hoyt and Langbein 1955).

In the forested West, precipitation is generally low in summer and high in winter. Exceptions are the frequent short-duration high-intensity summer rainstorms along the front ranges of the Rockies and on the Intermountain Plateau; occasionally there are similar storms over most of the mountainous West that produce damaging flows. In the far West, snowmelt floods occur nearly every year in late spring or early summer in some major basin draining the Rocky, Sierra Nevada, Cascade, or Olympic Mountains.

In the high rainfall zones of California, western Oregon, western Washington, and Idaho, early winter storms are the most frequent flood producers. Rain on low-lying or shallow snowpack produces the greatest floods. Snowmelt floods in the major valleys, usually in June, are second in frequency.

Three types of protective measures can reduce flood peaks or prevent increases in them. In order of increasing opportunity they are: management of existing forest land to reduce floods from rainfall, conversion of open land to forest, and snow management.

Forest Management and Rainfall Floods

Opportunities for moderating floods lie in management of timber, fire, and grazing.

Timber harvesting affects a large portion of the forest at one time or another. Soil disturbance from logging typically occurs on 10 to 40 percent of the area harvested. Extreme disturbance (77 to 88 percent of the logged area) may follow tractor logging and burning slash of old-growth redwood (Boe 1975). Three obvious ways to reduce stormflow are by reducing the disturbed area by choice of yarding method (Rice and others 1972), by rehabilitating logged areas that produce overland flow, and by providing filter strips between bared areas and streams. Keeping soil out of the channel is discussed below under "Management for Water Quality": this helps maintain channel capacity and channel bank stability and reduces the bulking of stormflows to a minimum.

Cutting trees reduces evapotranspiration and soil-water storage opportunity in season. Hence, for prevention of dry-mantle floods management of both private and public forests should aim at limiting the area of any sizable drainage that is subjected to heavy cutting at any one time and do whatever is necessary to insure rapid regeneration. It is also beneficial to increase the stocking of

trees in some existing stands to increase evapotranspiration and soil-water storage opportunity. The Water Resources Council (1968) has indicated needs for timber stand improvement on 9 million acres of federally owned land and on 20 million acres of non-federally owned land.

Wildfire burns over about 5 million acres of forest in the average year. Reduction of this acreage moderates flood damage, at least where intense fires are prevented or limited in areas that have high flood and sediment potential and slow or incomplete recovery of vegetation after fire. Fuel management (including burning and other measures) is important in prevention of wildfire damage. Besides helping to reduce the acreage damaged by wildfire, fuel management can reduce the impact on those areas where wildfire does occur. Conditions differ widely, even within regions and sometimes from year to year in the same area; however, we have stated some generalizations in various sections of discussing differences in regional fires and flood frequency.

Wildfire may occur infrequently on any area, but grazing is usually an annual harvest. About 85 million acres of forest are grazed. Since an estimated 20 million acres (about 4 percent of the total forest area) is grazed heavily enough to cause overland flow, grazing poses local flood problems but no widespread danger. Good watershed management (and good livestock management, too) must determine the safe carrying capacity of the forest range and then limit use to that capacity by using measures required to effect proper seasonal use and distribution of stock. This means eliminating grazing in some forest areas.

Conversion of Open Land to Forest

Research has amply demonstrated that the conversion of idle, eroding land to forest can sharply reduce peak flows over a period of 10 to 20 years. The dimensions of the job that needs to be done are indicated by the 35 million acres of commercial forest land that are less than 10 percent stocked and may need to be planted (U.S. Dep. Agric., For. Serv. 1965). A more recent estimate indicates that 22 million acres of understocked land need reforestation (Water Resources Council 1968). Even where these lands pose no massive flood threat, their rehabilitation would help to reduce flood peaks on tributary streams and would alleviate sedimentation problems downstream.

Snow Management

If floods from either snowmelt alone or from rainfall plus snowmelt originated on forest land, they are forest-influenced. The patterns in which forest trees are cut or left can influence snow distribution, melt rates, and snowpack influences on storage and delivery of rain (Anderson 1963, 1970a, Hoover 1971, 1973, Smith 1974). Although most forests probably are not managed primarily for flood prevention, the selection of cutting patterns and the scheduling of forest cutting may well be influenced by flood prevention objectives. The options are many, the effectiveness is great, and the objectives complement other objectives, such as water quality control.

Goodell (1959) explained that forest influences together with topographic influences can reduce flood peaks by desynchronization. Topography has the greatest influence on flood peaks. Snow on south-facing slopes characteristically melts earlier than snow on north slopes. Forest management can enhance this desynchronization by increasing the variability of melt rates over a large watershed. If, for example, the forest on a south-facing slope is managed to produce wide open strips running north and south, snowmelt should be seasonally early. If a north slope has dense continuous forest cover, the melt should be comparatively late. Thus, melt water from the south slope should be largely discharged before the north-slope yield reaches its maximum. Complexity arises on large watersheds where consideration must be given to the timing of discharges from numerous slopes differing in steepness, aspect, and elevation. Complexities arise in management for wet years and dry (Anderson and West 1966) and in slope exposure in areas that have different snow amounts or characteristics (Smith 1974, Warren and Ffolliott 1975).

Management for Maintaining Water Quality

Recent Federal and State legislation has given top priority to management for water quality control. Four Congressional acts with five amendments and recent presidential Executive Orders constitute the existing status of water quality legislation for United States surface waters. A particular concern has risen about nonpoint sources of deterioration of water quality, such as might be associated with forest roadbuilding,

treatment of logging residue, and preparation of sites for planting (Meier 1975).

Management of the quality of water from forest lands must rely on four basic steps:

1. Appraisal of the present and potential uses of water and how those uses would vary with different characteristics of water quality.
2. Appraisal of the present water supply and characteristics of its quality, including its natural variability.
3. Appraisal of the changes in quality that can be achieved by alternatives in management.
4. Appraisal of the value to beneficial uses of water that could result from alternatives of management.

Uses of water from forest land may be the crucial decision variable in forest land management. A local domestic water supply or local fishing requirement may dictate the direction and stringency of water quality management. On the other hand, the quality of water delivered to a downstream reservoir may seem to be equally crucial to a management decision, but may not be, for a filter plant could be installed to produce suitable improvement in quality. It has been said that "any water of improved purity will find a use", but the forest is there to use also (Lantz 1971b). Let us look at some of the characteristics of water quality supply from forests and then at the effects of management alternatives on water quality characteristics.

The forest has amazing capacity to buffer changes in the water's content of solids, dissolved inorganic chemicals, organic compounds, and microorganisms. Solid particles eroded from the soil surface in local areas may be filtered effectively by the forest floor or the forest soil together with other absorbed materials. The forest floor and forest soil naturally absorb both organic and inorganic chemical compounds; this was dramatically demonstrated by spraying massive quantities of domestic, industrial and agricultural wastewater on forest sites (Sopper and Kardos 1973). Nikolayko (1974) has documented the removal of microorganisms by the filter effects of the forest.

But natural forest systems do not necessarily produce the best quality of water for all uses: organic acids from forest litter may produce water high in calcium content in regions underlain with limestone, phenols dissolved from leaf fall in streams may produce undesirable odor or taste in the water, and water temperatures may be kept too cool for greatest production in the aquatic environment. Streamside vegetation may dry up channels. Local soil and climatic accidents such as landslides may produce occasional deterioration in water quality. At the same time that we consider maintenance of water quality we may consider enhancement.

The parameters of water quality subject to management could be any or all of the more than 40 listed by the Environmental Protection Agency (1972), but the ones currently being monitored from forest lands are generally turbidity, suspended sediment, pH dissolved oxygen, total dissolved solids, and temperature. Other parameters may include coliform bacteria, phosphorus, nitrates, certain heavy metals, and chlorides. The products of erosion contribute directly to several of these parameters and have received the most study.

Erosion and Sedimentation

It has been estimated that 80 percent of the deterioration in water quality is due to suspended sediment, mostly from soil erosion.

Forest cover strongly influences the volume of soil erosion and the influx of erosional products into streams and lakes. Man's activities in the forest often accelerate erosion and sediment production; this has long been recognized, and much has been written about the problem and how to prevent it.

Surface erosion, gully erosion, mass soil movement, channel erosion, and the transport of eroded material all degrade water quality. Suspended sediment damages municipal and industrial water supplies and also causes problems within the forest ecosystem itself. Dirty water degrades the aquatic habitat, reduces recreational use and enjoyment of the forest, and detracts from its visual appeal.

The magnitude of the problem of erosion control on forest lands depends on several considerations: soil disturbance, topography, and the nature of the soils, to name a few; each of these varies widely within any given region.

Basic statistics of the National Inventory of Soil and Water Conservation Needs (U.S Dep. Agric. 1962) show that about 1 percent, or 4.5 million acres, of the forest land in the East needs treatment to control erosion. Almost half of this area is in the Southeast (largely in Alabama, Georgia, and Mississippi), and more than one-

quarter is in the Central States (mostly Kentucky and Missouri). These estimates indicate that about 9 percent, or 7.5 million acres, of the forested West needs treatment to control erosion. Two-thirds of this area is in the mountainous portions of Arizona and New Mexico; most of the remaining third is divided about evenly between California and Oregon.

The severity of soil disturbance is often the prime factor in soil erosion. It is surely evident by now that an undisturbed forest soil promises a minimum of erosion. With some exceptions, surface erosion, mass movement, or channel cutting may be expected whenever mineral soil is exposed by logging, fire, or grazing.

Erosion Control—Logging

Erosion control begins with planning the road system and its drainage. The design of an erosion control drainage system requires information about the volume of water to be drained, the erosion potential of the subsoil, and the duration of use of the system (Engberg 1963). Since as much as 90 percent of the sediment produced by erosion on timber sale areas comes from roads (Packer and Christensen 1964, Megahan 1975), planning must begin with careful choice of logging methods appropriate to the area and with careful road location and design (Engberg 1963, U.S. Environmental Protection Agency and others 1975). Logging and skidroad mileage can be reduced by logging with skyline systems that reduce soil disturbance by about one-half of tractor logging. New equipment that can traverse roads having steep grades promises to make short access to ridgetop roads feasible, thereby reducing road erosion. In the future, balloon or helicopter logging may reduce soil disturbance even more (see the section on Timber Harvest and Erosion).

Slope-length relationships and frequency of use should govern road location. For example, a 4-percent grade may reduce drainage problems, but an 8-percent grade requires only half the length of road to reach the same elevation and may not tax modern vehicles. The time required for travel would also be shorter (Byrne 1963). Near the end of the road soil disturbance may be reduced by lowering road design standards to meet the expected reduction in road use (Banta 1963). Narrow roads with grades as steep as 20 percent have been used on low-use, dead-end spur ridges in an attempt to stay on the ridgetop and avoid the steep, thin-soiled headwalls and midslope locations. Side casting of road cut material on steep slopes may scour off shallow soils; in southwestern Oregon, end hauling to waste disposal areas has been proposed as a solution to this problem (Dittmer 1971).

In areas having diverse soils, a map of forest soils may be the basis for locating forest roads away from erosion-prone areas (Fisher and Bradshaw 1957). Similarly, identification of slide-prone areas from soil series and slope classes may enable avoidance of these major sources of erosion (Wallis 1963). The effects of road location and construction standards on sedimentation were clearly indicated in a recent study of deposition in reservoirs in 48 northern California watersheds. Streamside roads produced twice as much sediment as roads located on ridges or slopes; the greatest producers of sediment were improved secondary roads at streamside. Deposition increased 6.9 times for each mile of road per square mile of watershed above a reservoir (Anderson 1974). Road location is especially important in steep watersheds (Anderson 1976).

The control of road erosion requires not only proper location but cut and fill-slope protection and drainage necessary to prevent overland flow from developing enough depth and velocity to seriously erode the road surface and roadside ditches; Drainage must also prevent road runoff from reaching the stream channel directly. Surface flow has been diverted to roadside filter areas. Planting ponderosa pine on road fill slopes has effectively reduced surface erosion of fill slopes (Megahan 1974). Erosion from road fills and cut banks has been reduced by seeding, mulching, and fertilizing (Dyrness 1975, Berglund 1976). Mulching the surface is particularly important if erosion is to be prevented the first year after road construction, before vegetation becomes fully established.

But logging is more than roadbuilding. Prospects for maintenance of water quality by prevention of erosion associated with logging involves proper choice of a combination of silvicultural method, logging method, slash disposal, and post-logging treatments that will keep local erosion to a minimum (Rothacher and Lopushinsky 1974). Secondary effects must be controlled: augmentation of water yield, rapidity of snowmelt, and decomposition of forest floor material. Local erosion is being controlled chiefly by dispersion

of forest residues, installing crossdrains in skid trails, and seeding bare areas with grass; however, the control of channel erosion induced by the increased water yield or increased rate of snowmelt is only starting to be recognized and properly evaluated. Current evaluations involve selection of selectable increases in water yield associated with the area and type of cutting patterns (Galbraith 1975); then, the channel's tolerance must be appraised separately on the basis of a stability rating. If need be, the area to be logged is adjusted to meet the yield-stability criteria. One appealing prospect is to minimize the impact on the initial reach of the channel by making widespread, numerous small cuts or resorting to single tree selective cutting.

Part of the total problem of logging is disposal of the logging wastes that in steep forest area usually end up in stream channels; this poses another whole set of water quality problems.

Organic debris, which may vary from whole trees to simple organic compounds, poses varied problems to the forest manager. These problems vary from bulking and damming of flood flows to producing offensive odor in drinking water. The primary problems of water quality involve slow mechanical wear of debris in streams, dissolved solids affecting stream chemistry, and dissolved organic substances affecting water taste or odor. Secondary effects of the presence of organic debris in streams include such diverse things as interacting with sediment in the water, causing blocking of streams and scouring of streambanks, blocking of culverts, reducing stream oxygen, and effects on microorganisms in water action on their food chain. Some of these latter, in certain amounts, may be beneficial (Jackson 1975, Triska and Sedell 1975).

Presence of organic debris in streams along the Pacific coast raises special problems because this debris is present in large volumes, partly from natural causes and partly as a result of poorly planned or poorly managed logging operations (Rothacher 1959, Froelich 1971). Burns (1972) emphasized the need to keep all timber out of streams because decaying slash depletes intergravel oxygen. Low production of salmonids in clearcut watersheds of the Olympic Peninsula of Washington has been found to be associated with the large amount of organic debris in the streams (Allee and Smith 1974).

Froelich's outline (1971) of procedures for controlling the gross organic component of debris in streams essentially agrees with all other guides for eliminating pollutants from streams: the best control is simply to keep the pollutant out of the stream. Clearing debris out of channels, particularly channels of narrow streams, may actually cause more damage than leaving the stream alone (Burns 1972). Hewlett and Douglass (1968) found that most of the increase in sediment in streams on a multiple-use water shed resulted from stream "improvement" activity, including clearing. A study of 304 stream reaches in the upper Missouri River basins following the 1948 flood (Anderson and Ingebo (personal observation)) revealed that presence of debris did not reduce stability of first order tributary streams, whereas debris in stream links of higher order streams frequently caused scour of banks by forcing the flow to bypass it. Berry (1975) has concluded that reduction of oxygen in streams along the Oregon and Washington coast was closely related to length of clearcuts and temperature of the streamwater and suggests that cutting practices be modified by manipulating the length of clearcuts and leaving buffer strips instead of removing debris from channels.

Microbiological

A common index of the microbiological pollution in water is the coliform content. Prospects for reducing this index by forest management have been published in the Soviet literature. Drobikov (1973) reported that whereas streamflow from a clearcut area had (in summer) a coli index of 2300 to 9600, under the same conditions the index from selective group cutting was only 230 to 2300. Similar prospects for microbiological reductions may occur with choices of silvicultural methods in the United States in areas that have high summer rainfall.

Erosion Control—Fire

Erosion after severe fire is serious, especially in areas where low rainfall or repeated burning delay natural revegetation.

An extreme example of effects of fire on erosion is in the southern California and Arizona chaparral and has been discussed under that heading. Planting either herbaceous or woody species or both can often prevent some potential damage from erosion and sedimentation. The reforestation of 255,000 acres of the Tillamook

Burn in Oregon is an outstanding example of successful reforestation. Now, 25 years after the start of reforestation of part of the burn, trees are 50 feet high—already high enough for a commercial thinning (Oreg. Dep. For. 1973). The hydrologic consequences of reforestation are documented elsewhere in this paper. It is presumed that reductions in sedimentation were correlated with the reduced peak flows that followed reforestation because concentration of sediment in the watershed varies approximately with the square of the number of inches of streamflow.

Another technique for reducing the effect of wildfires on water quality is to use care in timing of post-fire treatments. For a short time, at least, the watershed is highly susceptible to other disturbance, such as road construction or salvage logging. The adverse erosion effects on the Tillamook Burn may have resulted from the post-burn logging and road building in the area described by Bailey and Poulton (1968). Megahan and Molitor (1975) suggest deferring salvage logging until dead needles dropped from trees can provide a ground cover to protect against erosion.

Regional Characteristics and Possibilities: The East

Regional differences in the relation of the forest to water yield, floods, and water quality result in different practices and possibilities for improvement. To assess these differences, we have divided the country into six major regions, three in the East, three in the West. We suggest certain practices that are based on research results already published and on climatic and streamflow data. These recommendations are not definitive; the selected regions are too diverse and the management objectives for even single watersheds too complex to permit statement of more than general characteristics and recommendations.

The three regions in the East and their characteristics are shown in *fig. 5* and *tables 12* and *13*.

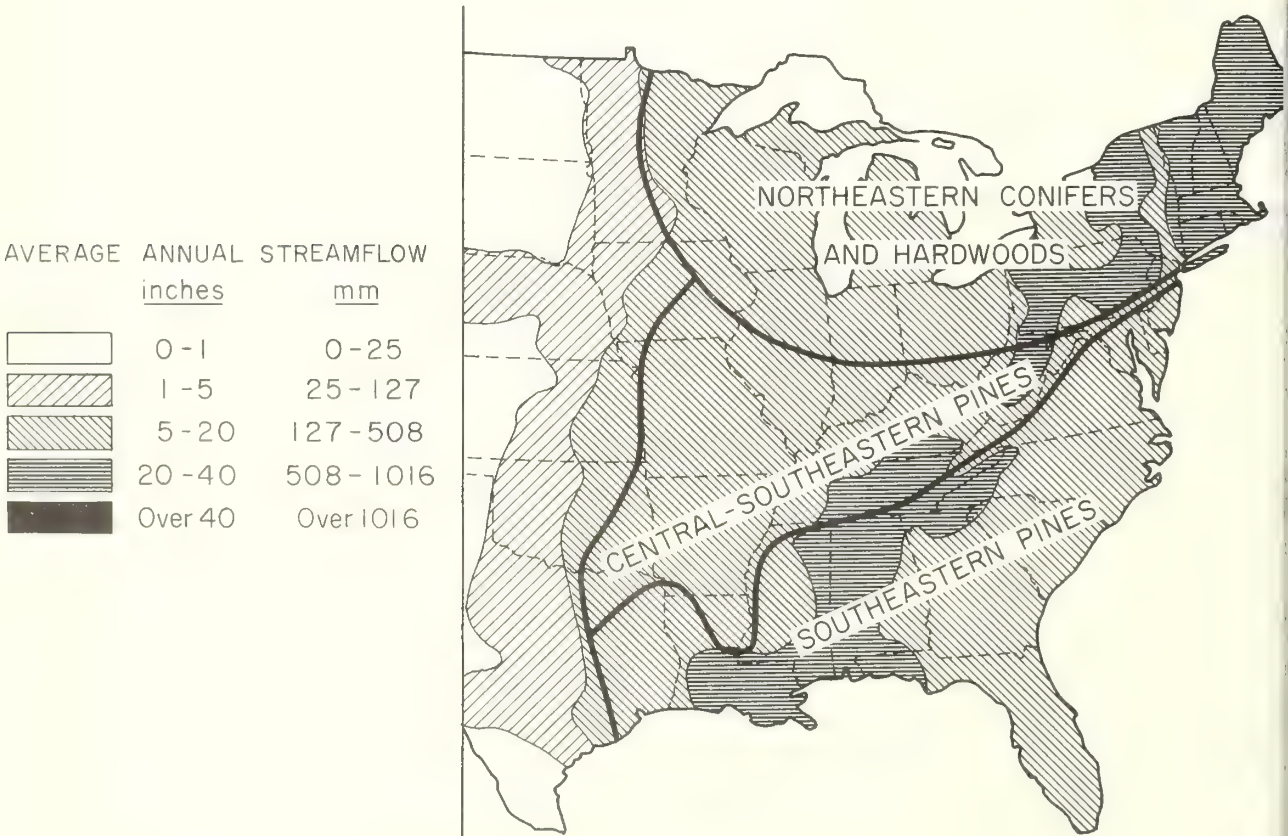

Figure 5—Major forest regions in the Eastern United States, and average annual streamflow.

Table 12—*Mean annual precipitation, streamflow, and evapotranspiration in selected forest types in the East, by geographic regions*

Region and forest type	Area	Mean annual . . .		
		Precipitation	Streamflow	Evapotranspiration
	Thousand acres	——— *Inches* ———		
	Northeastern Conifers and Hardwoods			
New England, New York, and Pennsylvania:				
White-red-jack pines	5,054	42	22	20
Maple-birch-beech	18,665	39	22	17
Oak-hickory				
Michigan, Wisconsin, and Minnesota:				
White-red-jack pines	4,435	29	10	19
Maple-birch-beech	9,630	30	11	19
Oak-hickory	6,170	30	10	20
Aspen	17,882	28	10	18
	Central and Southeastern Hardwoods			
Northwestern portion:				
Maple-birch-beech	3,416	44	19	25
Oak-hickory	61,051	40	16	24
Oak-gum-cypress	10,919	49	17	32
Southeastern portion:				
Oak-hickory	25,776	49	20	29
Oak-gum-cypress	25,884	50	13	37
	Southeastern Pines			
Southeastern area:				
Loblolly-shortleaf	52,008	49	16	33
Longleaf-slash	25,967	52	14	38

Source: U.S. Senate Select Committee on Water Resources 1960b.

The East has no areas of perennial water shortage, but occasional droughts cause severe local problems. Other areas have possibilities for increasing water yield enough to meet mounting domestic and industrial demands (Douglass 1974).

Water Chemistry and Temperature

Content of dissolved solids and water temperature are parameters of water quality; management attempts to keep each with certain limits. Dissolved solids content in streams flowing from forested areas are usually low and reflect mostly the local climate and geology. Stream-water temperature, of course, depends mostly on climate; but forest cover may moderate the effects of climatic extremes. Forest treatment can affect both of these characteristics of water quality; they cannot be ignored in forest watershed management, for how we change them can be important.

The principal technique for management for chemical water quality was emphasized by Tarrant (1972): "If you do not want the chemical in stream water, don't put it there!" Chemicals must be kept out of streams and other water bodies, and chemicals should be applied to land surfaces only where the possibility of their movement from land to water is low. The degree to which this has been achieved is stated in sections discussing applications of chemicals for specific purposes.

When timber is harvested, leaving buffer strips of uncut or lightly cut timber is probably the most effective means for preventing undesirable increases in streamwater temperature (Brown and

Table 13—*General characteristics of major forested regions in the East*

Characteristic	Regional forest type		
	Northeastern hardwoods and conifers	Central-southeastern hardwoods	Southeastern pines
(1) Forest area (thousand acres)	98,504	210,240	85,161
Major species	Maple; oak; beech; birch; eastern white, red, and jack pine; spruce	Oak, hickory, ash, maple, yellow-poplar, beech	Shortleaf, loblolly, longleaf, and slash pine
(2) Rainfall, max. 10-year 24-hour (inches)	3 to 5	4 to 10	6 to 10
(3) Freeze-free period, mean length (days)	90 to 150	120 to 330	210 to 330
Snowzone area (thousand acres)	76,740 (78%)		
(4) Flood damage:			
Total mean annual (million dollars)	284	893	419
(dollars/acre, all land)	1.06	1.46	1.41
Upstream mean annual (dollars/acre, all land)	1.57	2.57	3.24

Compiled as follows: (1) U.S. Dep. Agric. Forest Serv. 1965; (2) Hershfield 1961; (3) U.S. Dep. Commer. Environ. Data Serv. 1968; (4) Water Resour. Council 1968.

Krygier 1967). Brown and Brazier (1972) describe a method of designing buffer strips to provide optimum protection for the stream while achieving optimum utilization of timber.

The half of the entire Eastern region that is classed as forest yields roughly 500 million acre-feet of water per year through surface streams alone (Hewlett 1967a). Treating only 10 percent of this area could increase the yield by 10 million acre-feet of water annually, enough to meet the needs of an additional 50 million people. Because they are publicly owned, the 23 million acres of Federal and State forest lands that provide the highest water yields in the East may someday be managed with more emphasis on increasing their water yield.

Northeastern Conifers and Hardwoods

Precipitation in the Northeast ranges from 24 inches in Minnesota to 74 inches in New Hampshire's White Mountains (U.S. Dep. Commer., Environ. Data Serv. 1968). Snowfall averages 60 to 100 inches annually in the Lake States, but rainfall intensities in this region are the lowest in the East. Mean annual streamflow ranges from 5 inches in northern Minnesota to 20 inches or more in much of New England and New York (Busby 1966). The estimated mean annual evapotranspiration showed less spread, from about 18 to 24 inches.

Water yield—Mean annual precipitation, streamflow, and evapotranspiration by major forest types in the Northeast are given in *table 12* along with comparable data for other regions in the East. Streamflow is about twice as great in New England, New York, and Pennsylvania as it is in the Lake States for similar forest types, but evapotranspiration is about the same, around 20 inches.

Water conservation—Water might be saved by not planting trees adjacent to reservoirs, where in essence the plantings would become riparian vegetation; it has been estimated that this could save 1 to 6 inches per year in the Northeast. Herbaceous vegetation, which might be encouraged to promote soil stability in these areas, would consume some of this saving, but not all of it (Lull and Reinhart 1967). Where esthetically acceptable, cutting trees adjacent to reservoirs may save water.

In humid areas, riparian sites near streams may be shaded and cool, with a consequent

reduction in the potential for evapotranspiration, or sufficient water may be available for near-potential evapotranspiration over the whole watershed. A riparian cut here would have an effect no greater—possibly not as great—than a cut elsewhere.

Limited evidence from the East suggests that favoring hardwoods rather than planting conifers would increase water yield. Savings might amount to from 2 to 10 inches per year, or perhaps even more. On conifer plantations under intensive management (including periodic thinnings and intermediate and final harvests), the reduction in water yield from pine stands compared with yield from hardwood stands would be partially restored. If both water and timber values are compared, conifer plantations may often be preferable to hardwoods. Indeed, private landowners much prefer conifer stands because they yield cash benefits, but increased water yield brings no such benefits.

Clearcutting hardwoods and providing the minimum ground cover necessary for preserving soil stability may increase water yield by an amount equivalent to about half of the hardwoods' evapotranspiration, an annual increase that might range from 8 to 11 inches. Clearcutting under a sustained yield system that encourages immediate regrowth can increase the first year's water yield by as much as 4 to 14 inches. Clearcutting conifers may give as much as 4 inches' greater yield than cutting hardwoods. These increases diminish rapidly and almost completely disappear in about 10 years. Under an 80-year sawtimber rotation and even-aged management, the net increase in water yield could range from 0.5 to 0.7 inch annually. Of course, this is in comparison with water yield from a forest previously subject to no cutting at all; if the previous yield was affected by prior timber harvest or other forest removal, this increase would be reduced or eliminated.

If timber is taken from a watershed under a cutting system that removes timber uniformly over the entire area and creates only very small openings, there is some evidence that the increase in yield would be no more than about one-third of the increase that could be realized from block cutting the same volume of timber (Lull and Reinhart 1967).

For the northeastern region, Lull and Reinhart (1967) summarized the costs of achieving the maximum water yield that is consistent with maintaining a protective ground cover by removing fully-stocked, noncommercial stands. These costs were $100 to $200 per acre for clearcutting and $10 to $60 per acre for herbicide treatments, controlled burning, or bulldozing to further control vegetation. Combinations of treatments or retreatments might be necessary to establish and maintain the desired cover. The cost in terms of water yield could be an estimated 10 cents per thousand gallons or $33 per acre-foot.

Foremost among the potential management areas would be the 2 million acres of forest land in 14 northeastern States that comprise watersheds and reservoir-protection areas under the control of more than 750 municipalities, private water companies, and State and Federal agencies (Corbett 1970). The principal function of these areas now is to protect water quality; they also provide whatever income can be derived from harvesting forest products without reducing water quality.

Peak flows—The occurrence of highest flows in early spring rather than in winter is a distinguishing characteristic of the northeastern region (Miller and others 1962). The combination of spring rainstorms and snowmelt has produced record peak flows from New England's forested mountains. Peak flows and most of the annual yield usually occur together; 13 of the 23 inches of annual streamflow from northern New England's watersheds come during the spring months (Sopper and Lull 1965). However, occasional fall hurricane storms produce the highest local peak flows.

There is little question that stormflow is higher from cutover forest land, but mostly during the growing season (Lynch and others 1975, Corbett and Heilman 1975, Patric 1973). The few possibilities for reducing flood peaks from forested areas depend on logging practices that require a minimal area of road systems and landings and control overland flow from them. Another possibility is the reforestation of 8.5 million acres of nonstocked forest land. But where high spring temperatures may rapidly melt the snow accumulated under conifer plantations, planting conifers may occasionally serve only to increase peak flow on these occasions. In such areas, a combination of open land (with soil stabilized) and forest land may be preferable. Federer and others (1972) recently reviewed pertinent research, and concluded

that the possible effects of snow management on floods in the Northeast are small, that regional management is impossible because of the many ownerships, and that management of forests for protection from snowmelt floods need not be considered further in this region. According to another viewpoint, management should aim to preserve the existing diversity of land use, which serves to desynchronize peak flows from different parts of northeastern watersheds.

Sedimentation—The minimum sediment concentrations in the country are in the northeastern region (Rainwater 1962). Streams draining watersheds that have all types of land use average 280 p/m or less in most of this area, whereas streams in northern Ohio, northern Illinois, and southern Wisconsin average values as high as 2,000 p/m. Mean concentration is estimated at 390 p/m, equivalent at 10 inches of annual streamflow (in the Lake States) to 283 tons per square mile, and at 25 inches (in New England) to 707 tons per square mile. These sediment concentrations are far above acceptable standards for water quality; hence management of forest land to improve or at least not further impair downstream water quality is important.

Erosion on forested lands occurs only on areas where soil has been disturbed. Stony soils and the formation of erosion pavements in most of the region preclude prolonged soil loss. The 10,000-square-mile Driftless Area in southwestern Wisconsin presents the greatest erosion problem because of its highly erodible soils and steep topography.

In all of the Northeast, road design and maintenance are crucial to sediment control (Kochenderfer 1970). Spacing of cross drains and width of protective strips have been determined by the steepness of the road. Trimble (1959) recommended that maximum grades on truck roads or heavily used skidtrails on municipal watersheds should be less than 10 percent, except for very short stretches. Such roads can be drained adequately by cross drains spaced by this rule of thumb: divide 1,000 feet by the percentage road grade. With a 5-percent grade the drains would be 200 feet apart; with a 10-percent grade, they would be 100 feet apart.

The recommended minimum distance from road to stream in the White Mountains of New Hampshire is 50 feet plus 4 feet for each percent slope to the stream. Thus, on a 20-percent slope the road should be located at least 130 feet from the stream (Trimble and Sartz 1957). Water-spreading devices below the drainage outlet could make narrower strips acceptable.

The key to maintenance of good water quality in the northeastern forests, according to Trimble and others (1975), is intelligently regulated roads and application of known good logging practices; otherwise impairment of forest water quality is certain.

Chemical water quality—The study of nutrient discharge after clearcutting in New Hampshire showed concentrations of nitrate and some other ions in streamwater as high as 26 mg/l; this is the highest concentration found after clearcutting anywhere in the country (Hornbeck and others 1975, Pierce and others 1972). In the Fernow Experimental Forest, Aubertin and Patric (1974) reported that increases in nitrate-nitrogen concentrations in streamflow following cutting averaged about 1 mg/l or less. Increases at individual locations had comparable values. Similar results were reported by Lynch and others (1975) in a study in Pennsylvania. When only a small portion of any large drainage in areas like these is clearcut at any one time, nutrient concentrations do not increase enough to be a hazard to drinking water. However, even with this precaution, there might be a problem of local eutrophication, and probably temporary stream and lake eutrophication as well.

Central-Southeastern Hardwoods

The Central-Southeastern hardwoods region, largest of the six forest regions, extends from the 95th meridian across the Mississippi and Appalachians into the Coastal Plain. Mean annual precipitation is as much as 80 inches in part of the Appalachians but only about 36 inches at the western edge of the region; corresponding runoff for these areas is about 40 and 10 inches, respectively. The estimated evapotranspiration ranges from about 26 inches in the northern portion of the region to about 40 inches in northern Louisiana.

Water yield—For the upland types in this region, streamflow averages about 40 percent of precipitation; for the oak-gum-cypress type, the average is about 30 percent (*table 12*).

Clearcutting hardwoods in this region and maintaining a soil-stabilizing ground cover can increase annual water yield an estimated 8 to 14 inches in the northwestern portion and 12 to 16

inches in the southeastern portion; the first year after cutting, the yield may be 3 to 4 inches greater than this. In the southern Appalachians, streamflow increase after cutting is approximately twice as great from north-facing as from south-facing watersheds (Douglass and Swank 1975). If regeneration is immediate, this yield diminishes to a negligible amount through a recession period of 10 to 20 years. Again, under even-aged management, an 80-year rotation, and cutting a portion of each management unit every 10 years, the average annual increase in water yield in the northwestern portion of the region would be an estimated 1.0 to 1.6 inches. Thinnings and selection cuttings would increase water yield a little but only briefly.

The possibility of decreasing water yield from forests in the Southeast is real, if 20 million acres of upland hardwood forests were converted to southern shortleaf pines. Douglass (1974) has estimated that water yield would be reduced 8 inches per year, and that even if the pine forests were intensively managed they would use more water than the present hardwood forest.

Peak flows—In the North Central area, from 12 to 24 percent or more of the precipitation goes into stormflow, but only 4 to 12 percent in the Piedmont and Coastal Plain of the Southeast (Woodruff and Hewlett 1969). Winter is the principal season of high flows. One possible means of flood reduction is reforestation of the 15 million acres of nonstocked land. The present "nonstocked" classification means that these lands do not have silviculturally desirable trees. We do not know how much of it has other volunteer vegetation that serves some useful hydrologic function.

Sedimentation—The mean annual sedimentation rate for this region, coming from lands in all types of use, averages 814 p/m or 944 tons per square mile per year for a streamflow of 16 inches. Streams that drain loessial soils in the Mississippi basin have much higher average rates —as much as 6,000 p/m—and average rates up to 2,000 p/m occur in the Ohio River basin and the Piedmont Zone. Streams in the Appalachians and the Coastal Plain have low average rates, ranging up to about 280 p/m, similar to those in most of the Northeast.

As in other regions, poorly designed and located roads are the main cause of deteriorating water quality (Douglass and Swank 1975). During storms, turbidity is 10 to 20 times greater in a clearcut watershed with logger selected roads than in an undisturbed watershed. In undisturbed watersheds typical storm turbidity ranges from 20 to 30 p/m. However, in a watershed where roads were carefully designed and constructed, maximum turbidity increased tenfold (Douglass 1974). Apparently, in this area it is not enough to just declare that roads are adequately located and designed.

The self-healing process characteristic of northeastern soils is less prevalent in the Southeast; erosion once started on the deeper, less stony soils, continues for longer periods. This places even greater stress on need for careful location, construction, drainage, and maintenance of logging and skidding roads and on the stabilization of road cuts and fill banks. Tree planting has major importance in site rehabilitation and sediment control.

Three opportunities for improvement in water quality in the South through erosion control have been suggested. First, reforestation of 15 million acres of depleted upland hardwoods should reduce erosion. Ursic and Dendy (1965) measured five times greater soil losses from these depleted hardwood forests than from mature pine-hardwood forest. Second, erosion can be reduced during mechanical site preparation for forest planting, which is a chief source of accelerated erosion in the South (McClurkin and Duffy 1975, Dissmeyer 1976). Planting a quick growing cover crop is one method. Third, erosion can be reduced by prevention of overgrazing of the hardwood forests, which is another serious source (Dissmeyer 1976).

Reforestation with pine often takes 10 years to produce a litter cover sufficient to protect the soil. Duffy (1974) combined grass and pine planting; by deferring fertilization, he reduced grass competition with pine sufficiently to allow pine establishment.

Southeastern Pines

The southeastern pine region includes portions of the Piedmont and most of the Coastal Plain. Annual precipitation ranges from 40 inches on the western edge to 60 inches along the Gulf Coast. Rainfall intensities in this region are the highest in the East. The mean annual streamflow ranges from about 10 to 30 inches, and evapotranspiration from about 30 to 40 inches.

Water yield—Mean annual precipitation for both major types of pine (loblolly-shortleaf and longleaf-slash) averages 50 inches, streamflow 15 inches, and evapotranspiration 35 inches (*table 12*). Hewlett (1972) pointed out that although the Coastal Plain areas generally have abundant water, the ridge and valley provinces find water in rather short supply.

Clearcutting southern pine may increase annual water yield by 16 to 18 inches (about half the estimated evapotranspiration) after a protective ground cover develops. The maximum increase the first year may amount to 19 to 22 inches. During regrowth of a forest stand, measurements of soil water suggest that increases in yield may persist for 15 to 20 years and the immediate reduction may not be as sharp as when sprouting hardwoods utilize established root systems. We have already pointed out that even-aged management (an 80-year rotation with parts cut at 10-year intervals) can increase the average annual water yield by 1.4 to 1.6 inches. Likewise, thinnings and selection cutting may be more effective in increasing water yield in pines than in hardwoods (Rogerson 1971). Since pines do not sprout from the stump, reoccupation of the site may therefore be slower.

Douglass (1974) pointed out that although water quality is emerging as a primary problem in the South, water yield management is an important part of quality management.

Peak flows—Winter months (January, February, March) and hurricane months (September and October) are periods of highest flows. Deep, permeable Coastal Plain sands contain and slow the movement of flood-potential rainfalls into streamflow. The Piedmont produces more stormflow, but under the undisturbed forest, the deep soils also hold flood flows to a minimum. Hewlett (1967b) estimated that only 4 percent of the precipitation falling in the Sand Hills and Upper Coastal Plain of Georgia was yielded as stormflow; in the Piedmont it was 10 percent, and in the northwestern Ridge and Valley lands, 15 percent. Several studies have shown that peak flows from eroding idle land can be reduced drastically by establishing deep-rooted vegetation. This appears to be the most effective method of reducing local flood peaks.

Sedimentation—The mean annual sedimentation rate (from all lands in all uses) is about 650 p/m, or 850 tons per square mile for an annual streamflow of 18 inches. The Coastal Plain forest has few sedimentation problems; its most turbid streams average only 280 p/m. The Piedmont is the problem area; some streams there average 2,000 p/m. Logging on Piedmont soils may start erosion that can seriously damage both site and streamflow. With care, however, pine stands on highly erodible soils can be logged without causing serious loss of soil.

Pines are widely used to control erosion. On areas that are not eroding very severely, planted pines can stabilize the soil, develop a forest floor that will facilitate infiltration, and control overland flow in a few years. Where only infertile soils remain, or where ground slopes are steep or eroding badly, seeding for herbaceous cover or mechanical erosion control should accompany or precede pine planting.

Regional Characteristics and Possibilities: The West

Western forests range from semiarid to subhumid. In the semiarid West, the demands of cities, agriculture, and industry for more water from higher-elevation forest areas have generated growing interest and some action programs to increase water yield by forest cutting.

Opportunities appear most favorable on about 15 percent of the area of the 17 states west of the 100th meridian. This 15 percent includes 116 million acres of high-elevation forest land, 22 million acres of chaparral, and 16 million acres of phreatophytes. The maximum possible increase in yield from forest cutting in the West is estimated at 12.5 million acre-feet annually (U.S. Senate Select Committee on National Water Resources 1960b). If we include the potential increase in water yield resulting from clearing of phreatophytes, a goal of 25 million more acre-feet would not appear unrealistic.

The full potential would seldom be achieved. For example, the potential for the lodgepole pine and Englemann spruce-fir types is an estimated 3.8 million acre-feet. According to one assessment, if these types are managed for sawtimber only, with water yields incidental, the increase would be 385,000 acre-feet; if managed for pulpwood, the increase would be 962,500 acre-feet; or if managed principally for water, cutting every 25 years to give an average annual increase of 1.5 inches, the average annual increases would be 1,925,000 acre-feet (U.S. Senate Sel. Comm. on Natl. Water Resour. 1960b). Such increase may

now be practical because in these timber types the pattern of cutting that favors water yield is also silviculturally desirable (Leaf and Alexander 1975).

National Forests offer the greatest possibilities for increasing forest water yield. These forests occupy 21 percent of the area of the 11 Western States, receive 32 percent of the precipitation, and produce more than 50 percent of the total streamflow. Their average annual flow is 14 inches, compared to the 3-1/3 inches from areas outside the National Forests. The greatest water producer is the snowpack part of the commercial forest zone, where precipitation ranges from 20 to more than 100 inches annually and much of it becomes streamflow. More than a half million acres of this zone is cut over annually, providing a substantial water increase.

Even in water-short areas of the West, however, management cannot consider water yield alone. Floods are also a problem. History shows that the cumulative effects of burns and reburns on large and small watersheds have posed a constant and widespread flood sedimentation threat. The 100-mile swath across Montana and Idaho left by the 1905 fire and subsequent reburns is still partly unstocked or understocked; the Yacolt fire in Washington and the Tillamook fires in Oregon left huge devasted areas. In all of western Oregon, logging and burning had left only 15 percent of the logged forest "well stocked," according to a detailed survey in 1947 (Anderson 1952). In 1970 the Sky Harbor and 2,000 other fires, started by a single lightning storm, burned more than 200,000 acres in central Washington. In view of the known long-term effects of fire on western watersheds, we must expect hydrologic problems from these recent conflagrations (Anderson 1976b).

Snowmelt and rain-on-snow have produced some of the largest floods in the West. Availability of snow and the frequency and amount of rainfall determine the potential hazard. In western Oregon, for instance, the combination of the two places the greatest potential hazard at elevations between 2,000 and 4,000 feet. This is the zone, therefore, where flood protection is most needed (Anderson and Hobba 1959).

Erosion and its consequences in deteriorating water quality are management problems throughout the West; logging roads and skidtrails must be planned in advance to reduce both length and gradient (Silen and Gratkowski 1953, Mitchell and Trimble 1959). Planning also includes locating cutting areas and landings before logging begins. Landings should be so located as to minimize yarding across streams (Dunford 1962). In the western snow zone, measures to minimize sediment production include patch or contour stripcutting on steep slopes, leaving strips of trees adjacent to the channels of headwater streams, keeping road fills away from streams, revegetating road cuts and fills, diverting road-drainage water away from stream channels, keeping landings out of drainages, diverting water from skidtrails after their use, and removing temporary stream crossings (Anderson 1966). Sedimentation damage from floods in the Pacific Northwest has led to recommendations for intensive planning: "To minimize damage to the forest transportation system, roads and bridges must be planned, designed, constructed, and maintained with adequate recognition of soil stability problems. . ." (Rothacher and Glazebrook 1968). Specific items include retaining walls where necessary to reduce fill embankments, grade dips as a safety measure in case culverts or ditches become blocked, trash racks to reduce culvert plugging, and gabions to minimize bank erosion at stream crossings.

Detailed recommendations for the control of sediment from logging roads have been developed for the Intermountain and northern Rocky Mountain regions (Packer and Christensen 1964, Packer 1967b), for forest and brushland zones in California (Kraebel 1936), and for the Douglas-fir region of the Pacific Northwest (Society of American Foresters 1961, Rothwell 1971, Burroughs and others 1973, U.S. Environmental Protection Agency and others 1975).

The three major forested regions in the West and their characteristics are shown in *fig. 6* and *tables 14* and *15*.

West Coast Forests

The West Coast forest region, the smallest of the six, features the highest annual rainfall, the deepest snowpacks, and the largest trees. The coastal mountain ranges receive the entire range of annual precipitation, 40 to 150 inches (U.S. Dep. Comm. Environ. Data Serv. 1968); most of this precipitation comes as rainfall. Eastward, the main Cascade Range and the Sierra Nevadas have a similar range of precipitation, but most of it comes as snow. Rainfall intensities range from 6

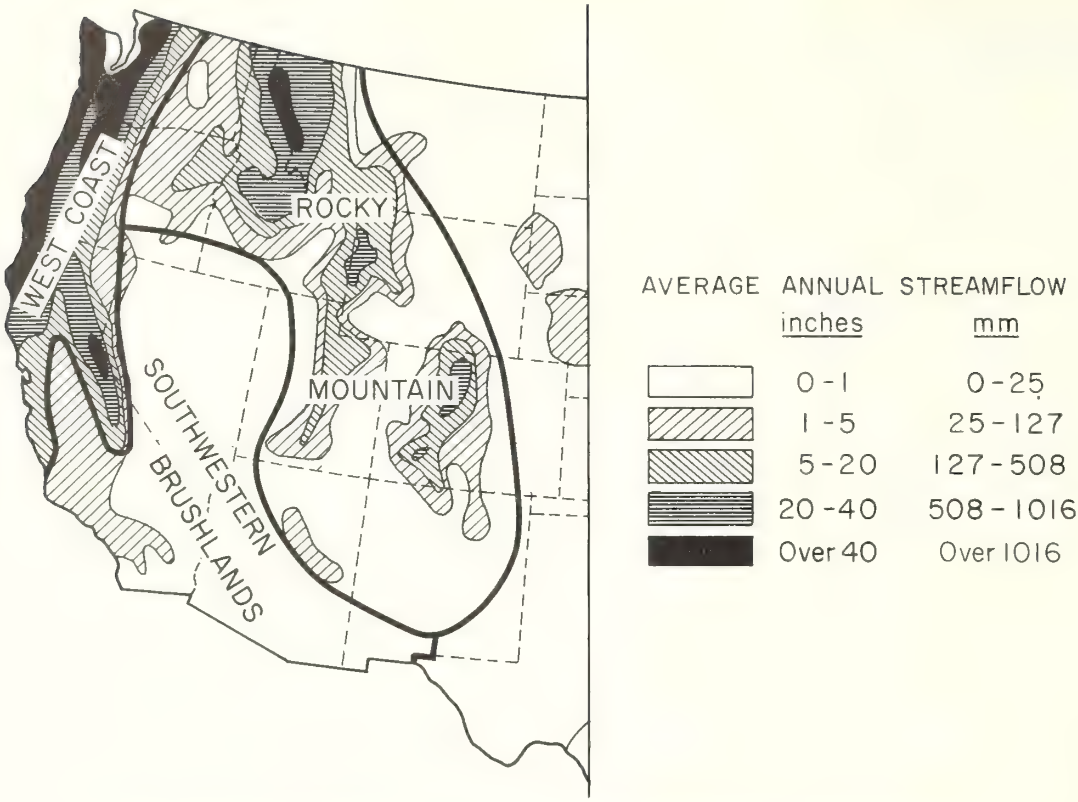

Figure 6—Major forest regions in the Western United States, and average annual streamflow.

Table 14—*Mean annual precipitation, streamflow, evapotranspiration, and potential increase in water yield of selected forest types in the West*

Region and forest type	Area	Mean annual . . .			Potential increase in yield
		Precipitation	Streamflow	Evapotranspiration	
	Thousand acres	*Inches*			
West Coast					
Mixed conifers	8,470	44	22	22	4.5
True fir	6,150	60	36	24	6.0
Douglas-fir, hemlock, redwood	25,570	75	45	30	15.0
Rocky Mountain					
Lodgepole pine	14,470	33	14	19	3.0
Englemann spruce, fir	7,400	33	18	15	3.0
White pine, larch, fir	6,900	42	20	22	4.5
Aspen	4,000	33	10	23	3.0
Ponderosa pine	34,200	21	4	17	0.5
Douglas-fir	9,000	28	7	21	1.0
Southwestern brushland					
Southern California chaparral	7,500	25	5	20	1.0
California woodland, grass	9,000	25	7	18	1.0
Arizona chaparral	5,500	19	1.5	17.5	0.5

Source: U.S. Senate Select Committee on Water Resources 1960b.

Table 15—General characteristics of major forested regions in the West

Characteristic	Regional forest type		
	West-Coast forest	Rocky Mountain forest	Southwestern brushland
(1) Forest area (thousand acres)	36,446	140,818	52,000
Major species	Douglas-fir, western hemlock, redwood, true firs, pines and spruces	Ponderosa, lodgepole, and western white pine; Douglas-fir; true firs; spruces; and aspen	Chaparral, pinyon and juniper, phreatophytes
(2) Rainfall, max. 10-year 24-hour (inches)	2 to 10	2 to 4	2 to 12
(3) Freeze-free period, mean length (days)	90 to 330	30 to 150	90 to 330
Snowzone area (thousand acres)	27,187 (75%)	129,303 (92%)	5,184 (10%)
(4) Flood damage:			
Total mean annual (million dollars)	292	306	222
(dollars/acre, all land)	2.47	0.79	0.94
Upstream mean annual (dollars/acre, all land)	5.19	1.51	2.73

Compiled as follows: (1) U.S. Dep. Agric. For. Serv. 1965; (2) Hershfield 1961; (3) U.S. Dep. Commer. Environ. Data Serv. 1968; (4) Water Resour. Counc. 1968

to 10 inches in 24 hours, at a 10-year frequency along the coast, to 2 to 8 inches on the upland ranges. The snowpack, a principal source of water supply, occupies in season most of the main ranges of the Cascades and the Sierra Nevadas.

In these areas, reservoir storage is a typical way of prolonging delivery of water. Reservoirs become particularly important in forest management for improvement in water supply. Water delayed in delivery from snowpacks can refill reservoirs depleted by earlier withdrawal for irrigation; water saved by manipulating vegetation or a variety of other techniques can replenish reservoirs in dry years or seasons. The basic problem is to make sure that the management applied is compatible with other land uses, water uses, and water control and that the techniques are applied where and when they will be the most effective.

Water yield—Mean annual precipitation, streamflow, evapotranspiration, and potential increase in yield for the western region are given in *table 14*. The potential increase in water yield, based on cutting patterns that would increase the snowpack yield, is equivalent to about one-fourth of the calculated evapotranspiration, or 3 to 6 inches. Studies of the effects of clearcutting in the red fir type in California (Anderson 1969) and the Douglas-fir type in Oregon (Rothacher 1970) have given estimated annual increases of 12 and 18 inches, respectively.

Patch-cutting (with roads) of 30 percent of a watershed in the Douglas-fir type in Oregon increased water yield about 8.5 inches per year over a 5-year period (Rothacher 1970). In the red fir type, first-year water savings estimated at 12, 9, and 6 inches may be derived from strip cuts, block cuts, and selective cuts, respectively (Anderson 1969). Where the objective is maximum snow accumulation and maximum delayed melt, a wall-and-step cutting pattern has evolved. To achieve the pattern in the mixed conifer forest of the California Sierra Nevada the cut strips should be oriented according to topography: Generally, these strips should run east-west on north and south slopes, northeast-southwest on east slopes, and northwest-southeast on west slopes. This arrangement maximizes the shade during that portion of the day when the sun's rays are most nearly normal to the sloping surface. Successive strip cutting, proceeding southward, would then provide a wall of mature trees for shade and would minimize back radiation. The width of strips on south slopes steeper than 20 percent should be about one-half tree height (at rotation age). Strips are spaced according to the

number of cutting cycles in a rotation (Anderson 1956). A test of this pattern, where the strip was located so that residual small trees formed the "step," showed a 25-percent increase in snow accumulation. Seventy percent of the increase persisted well into the melt season (Anderson 1963).

Opening the forest in the West has relatively long-lived effects on yields of snow and water; increases probably last 20 or more years. Savings in interception losses may persist to the culmination of the leaf surface on regrowth, about 35 years.

Others areas subject to management for improved water yield include northern California, where there is major opportunity for conversion of brushlands to productive forests, and where water benefits add to the justification. In the high-elevation zones of the Sierra Nevada west-side, for example, 2 million acres of large brushfields could be converted to forest, saving 11 inches of water during the conversion process and ultimately improving management of snowmelt (Anderson 1963).

Peak flows—In the coastal range, highest flows come during the winter months, a result of heavy rainfall on wet-mantle soils. Both the magnitude and frequency of floods appear to be increasing as timber cutting extends through the redwood region (Lee and others 1975). Logging various portions of a watershed on a staggered schedule may possibly change the times of concentration and reduce peaks. Control over the location, design, and maintenance of logging roads, skidtrails, and landing—along with treatment of these areas after use—is necessary to reduce overland flow.

Three types of floods originate in the snowpack zone: from snowmelt, rain on snow, and rain. Rain and rain on snow produce the largest floods. The effects of management on floods depend on the kind of flood and the kind of mangement. By altering the timing of water yield, for example, management may also reduce peak flows (Anderson 1963).

In the Sierra Nevadas of California, for example, periodic snowmelt floods occur as late as June. A dense uncut forest may contribute about 12 inches less water with a much slower melt rate: the snowpack on April 1 may contain the equivalent of 50 inches of water, and melting may continue until the end of June. Large openings, on the other hand, may contain an additional 5 to 10 inches of water, and melting may be enough more rapid that it will cease early in June. The timing of snowmelt in selectively cut areas differs between low and high snowpack years. Because the degree of snychronization of snowmelt from many parts of a watershed determines the size of floods, management practices that augment or diminish such synchronization will increase or reduce snowmelt flood peaks.

According to Anderson (1966), maximum flood protection results from:

a. *Maintaining maximum use of water by vegetation*

   No cutting, selective cutting, strip-cutting on the contour, and other types of cutting, in that order, and maintaining deep-rooted vegetation on deep soils and adjacent to stream channels

b. *Maximizing lengths of water flow paths*

   Maintaining surface infiltration and deep percolation, preventing soil freezing, and draining roads away from stream channels

c. *Maximizing diversity in timing of snowmelt*

   Selective cutting on south-facing slopes coupled with no cutting or strip-cutting on north-facing slopes, and encouraging the formation of snowdrifts with natural or artificial barriers

Sedimentation—Sediment concentrations in rivers differ greatly over most of this region, ranging from 50 to more than 2,000 p/m for watersheds that drain both forest and nonforest lands. In the northern California brushfields, manzanita provides the best soil protection and chamise the poorest. In gently sloping areas, soil is best protected by removing the brush and seeding to grass; erosion rates increase temporarily until the grass is established (Burgy 1958).

The mean annual turbidity (again averaging for all types of land use) is about 54 p/m in western Oregon and 470 in northern California. Average turbidity ranges from 12 to 220 p/m in Oregon and from 8 on the Sierra east-side to 20 on the west-side and as high as 2,000 p/m in north coastal California. In the redwood Douglas-fir forest, excessive disturbance of soils by logging can increase sedimentation eightfold. If revegetation is rapid, sediment concentration decreases rapidly about 3 years after the logging, but large storms may bring back instability and result in further high concentrations of sediment (Fredriksen 1970, Anderson 1970b). Erosion

accelerates most on landings, skidtrails, roads, and on the landslides that they may trigger. Proper location, maintenance, and closure of these disturbed areas can reduce sedimentation from these sources to a minimum. However, in unstable stream channels any sources of augmented streamflow—independently of control of erosion at such sources—may be expected to increase sedimentation (Anderson 1975c).

In the Northwest, combination of 25-percent patch cut with slash burning in a watershed with logging roads showed a 6-year average sediment concentration 48 times that on an undisturbed watershed, whereas a complete clearcut without roads had only about a 5-fold increase. Six-year average concentrations of sediment were 9, 48, and 430 p/m respectively in the unlogged, clearcut and patchcut with roads (Fredriksen 1973). Maximum 1-day concentrations showed about equal proportions: 220, 1,000, and more than 10,000 p/m. Fredriksen concluded that practices that reduce soil disturbance by logging or slash burning should be encouraged; these favor rapid regrowth of vegetation and reduce deleterious impacts on water quality in forests that receive heavy rainfall.

Erosion is a lesser problem in the snowpack zones in most years because the snowpack protects the soil from the impact of rainfall, and melting snow seldom generates overland flow. After the snowpack disappears, the principal sources of sediment are areas bared by logging, land slippages associated with logging, road cuts, and burned areas. Heavy grazing may cause small increases in sediment production. Procedures for controlling erosion from logging have already been described; emergency contour trenches have controlled overland flow and sediment discharge from burned watersheds during short, high-intensity rains (Copeland and Croft 1962). C.H. Gleason, in a personal communication about 1963, reported that, as in southern California, trenches sometimes failed when flows from winter rain exceeded their surface storage capacity. Periodically rainstorms at high elevations find little or no snow, and local erosion can be high in such snow zones (Anderson 1963), for soils in these high elevation zones are less resistant to erosion (Willen 1965).

Landslides—In the Pacific Northwest, where roads, and to a lesser extent logging, are responsible for accelerated mass soil movements, landslides can be reduced by locating roads so as to avoid unstable soils and landforms (Fisher and Bradshaw 1957, Wallis 1963, Rothwell 1971, Burroughs and others 1973), by using skyline, or possibly balloon logging in steep, mountainous terrain, and by adjusting streamflow increases so as not to exceed channel capacities. Adequate road drainage and avoidance of sidecasting on steep slopes also reduces the hazard of mass movement (Dyrness 1967a). Landslides have also resulted from the conversion of brushlands to grassland range in California (see the section, "Type Conversion"). Landslides occur sporadically even in undisturbed steep forest lands. Swanston (1969, 1974) and Rice and Krammes (1971) have summarized the nature of mass movement problems in forest lands, some methods of evaluation, and possible management techniques.

Rocky Mountain Forests

The Rocky Mountain forest area (*fig. 1*) extends nearly the whole length of the western United States from central Arizona and New Mexico in the south to beyond the Canadian border to the north. A dozen major types of forest contribute to streamflow from river systems from the Columbia to the Rio Grande and thus are the principal source of water for irrigation of semiarid lands and power developments for the whole West. Something of the vegetation types and general forest hydrology have been described recently in a series of papers. Hibbert and others (1974) have described the south chapparal zone, and Clary (1975) has described the pinyon-juniper zone. H.E. Brown and others (1974) and Baker (1975) have outlined the prospects for water yield from the ponderosa pine forests of Arizona in relation to other multiple-use objectives. Rich and Thompson (1974) have outlined opportunities for increasing water yield in the mixed coniferous zone of Arizona. Overall prospects for increases in water yield in Arizona have been estimated by Ffolliott and Thorud (1975). Leaf (1975a) has summarized the opportunities for watershed management in the principal vegetation types of the central and southern Rocky Mountains. More detail was given by Martinelli (1975) for the Alpine zone; by Hoover (1973) and Leaf (1975b) for the subalpine zone; by Gary (1975) for the ponderosa pine zone of the Colorado front range; by Orr (1975) for the ponderosa pine and white spruce forests of the Black Hills; and by Sturges (1975) for big sage country. Copeland (1969) summarized the possibilities for water manage-

ment for the coniferous forests of the northern Rocky Mountains.

Water yield—The opportunities for management for water yield in several of the vegetation types of the Rocky Mountains are unusual. Nowhere would the projected use be greater if the demand could be met (Cochran 1974). Demands for water are for energy production, coal gasification, for retrieval of oil from shale, for rehabilitation of mining waste sites, and for maintenance of aquatic habitat. Nowhere is there more compatibility between water management and management of other resources. Since timber regrowth is slow, water yield increases with timber cutting and lasts 3 to 5 times as long as in other areas (Hoover 1973); brushland may be converted to more profitable grassland with a saving in water (Brown and others 1974); alpine snowfields may be manipulated to yield prolonged flow in summer (Martinelli 1975); the vast area (196 million acres) of big sagebrush could be cleared to produce extra water (Sturges 1975), and use of water by phreatophytes and riparian vegetation along streams could be salvaged (Horton and Campbell 1974). Conventional silvicultural practices seem to be compatible with water yield objectives; in addition, evaporation suppression, melt retardation, creation of artificial glaciers, water harvesting from impervious areas, and cloud seeding may be used to increase water yield.

An increased water yield of 3 to 4 inches can be obtained from the subalpine coniferous forest by removing 30 to 50 percent of the total stand in small, well distributed patches. These patches should be less than eight tree heights in diameter; uncut groups of similar size should be left standing for maximum efficiency (Hoover 1973).

The persistence of increases in water yield following cutting of lodgepole pine was indicated by measurements of water yield following the cutting in Fool Creek Experimental Forest. The trend line of expected increase (Leaf 1975b, *figure 11*) indicates an initial increase (in 1956) of 4.5 inches and subsequent decline of increases at the rate of 0.1 inch per year for the 17 years of record. If this trend persisted for 45 years, there would be a possible total increase of 101 inches, or 8.4 acre-feet of additional water per acre of the managed forest.

Less is known about possibilities for improving water yields from aspen forest. Soil-water studies to date suggest that replacing aspens with shallow-rooted vegetation would increase yield where soil depths exceed 4 feet (Brown and Thompson 1965). Cutting openings will increase snow storage in the opened area by one-third (Swanson 1973).

Although not part of the Rocky Mountains proper, the Uinta Mountains of northeastern Utah may afford similar opportunties for mangement for water yield. The area has about 563,000 acres of lodgepole pine forest. Johnston (1975) reported that clearcutting of lodgepole pine resulted in some 4 inches of water remaining in the soil at the end of summer, water "available for streamflow."

Below the subalpine zone in the Rockies lie the ponderosa pine and Douglas-fir forests. Ponderosa pine grows on south and west slopes at elevations of 3,000 to 5,500 feet in the northern Rockies above the sagebrush type, and at 5,500 to 8,500 feet in the Southwest above the chaparral and pinoyn-juniper types. Douglas-fir predominates on the cool, moist north and east slopes, and on south slopes at the upper edge of the ponderosa pine zone. Ponderosa pine covers 34 million acres and Douglas-fir 9 million acres. Average annual precipitation ranges between 21 to 28 inches; the average water yield is 4 inches from ponderosa pine forest and 7 inches from Douglas-fir. Small increases in water yield (0.5 to 1.0 inch) are attainable on deeper soils by harvest cutting but somewhat more from strip and block cutting (Brown 1971, Rich 1972, Rich and Thompson 1974, H.E. Brown and others 1974, Gary 1975). Irregular patch cutting has been recommended for cutting in the ponderosa pine forests in the Black Hills (Orr 1975).

At elevations between 4,500 and 8,000 feet scattered over 43 million acres in the 4-corners states and Nevada is the pinyon-juniper type. Present prospects for treatment of this type to increase water yield are limited by adverse environmental considerations of the known techniques (Clary 1975).

At the lower elevations below the pine and juniper stands there are about 169 million acres of big sagebrush that are susceptible to special techniques for improving water yield (Sturges 1975). Much of this area, particularly in Wyoming, is characterized by periods of drifting snow, and techniques for saving water from this source have been perfected (Tabler 1975). Rechard (1973) has estimated that in Wyoming alone some 2 1/4 million acre feet of water could

be saved annually — 1 1/4 million by use of snow fencing and another million by spraying sagebrush.

The best prospects for substantially increasing water yield in dryer areas are by confining or extending clearcutting to streamside areas of supposedly high water use. Relatively large increases can be obtained from the riparian zone, provided evapotranspiration is much higher there than on the rest of the watershed; e.g., where trees and shrubs line water-courses and are exposed to bountiful energy advected from surrounding open or brush-covered terrain. This condition is exemplified by the phreatophyte areas of the arid and semiarid West. After describing the many types of riparian conditions, Horton and Campbell (1974) have concluded that despite this wide diversity, "Only rarely in the Southwest are there phreatophyte areas that would be best managed by complete preservation." Vegetation zones in arid land often are susceptible to adverse effects of treatments on sedimentation; special precautions may be needed in managing these zones.

Peak flows—Spring floods that originate from melting snow in the forested snow zone are normally a minor problem in the Rocky Mountains. Occasionally major upslope or convective storms dump large quantities of rain during May and June in the foothills below the snow zone. The normal high runoff from spring snowmelt can aggravate the flooding from such storms. Good cutting practices and the exploitation of topographic influences for protection can reduce peaks by prevention of overland flow and desynchronizing snowmelt (Goodell 1959).

An example of delayed melt was studied in northern New Mexico. Surveys of snowpack conditions there have suggested that at elevations near 9,900 feet, management to delay melting should favor Douglas-fir over aspen. At elevations near 11,150 feet, management to delay melting should favor spruce-fir cover and limit cutting in old growth stands, particularly on south-facing slopes (Gary and Coltharp 1967).

At lower elevations, especially along foothills below 8,000 feet, cloudburst floods are common in the summer months. The greatest floods occur when high-intensity storms strike watersheds after ponderosa pine forests or shrub cover has been burned or severely overgrazed; therefore, protection from fire and overgrazing is important in forest mangement there.

Sedimentation—The mean annual sedimentation rate for the Rocky Mountain area is 7,000 p/m, or 1,100 tons per square mile at 2.25 inches streamflow. Most of the forest region, however, has a maximum rate of 280 p/m, the same as the preponderance of forest areas in other regions.

The snowpack forest produces little sediment in the central Rockies. Snowmelt seeps directly into the soil without eroding it; therefore, streams usually are clear at high elevations. In the northern Rockies periodic rain or rain on snow can produce high volumes of sediment. To keep erosion from logging to the minimum requires preplanning the road system, patch or contour strip cutting on steep slopes, supervision of logging, revegetation of road cuts and fills, careful location of landings, and postlogging care (Noble 1961, Megahan and Kidd 1972, Megahan 1975).

Erosion can be severe at lower elevations wherever soil is exposed by logging or fire. Nearly all the soils in this region are highly erodible. High-intensity rainfalls have produced major debris flows. Much of the sediment is torn from gullies and channel banks. Contour trenching has been used successfully along Utah's Wasatch Plateau to contain overland flows that formerly generated mud-rock flows. Seeding perennial grasses on a burned-over ponderosa pine area in Arizona immediately after fire stabilized the area (Rich 1962). Prevention of fire and avoidance of severe logging disturbance are, of course, more effective in controlling erosion than corrective measures applied later. In the Front Range, improved logging practices and methods of gully control are needed (Heede 1975, Gary 1975); in the northern Rocky Mountains, controlling erosion from roads is the current major problem (Megahan 1974), and control of water quality and esthetics associated with mining are growing concerns (Johnston and others 1975, Jensen 1975).

Southwestern Brushlands

There are 22 million acres of chaparral and woodland in the Southwest, 15 million acres of pinyon-juniper, and 15 million acres of riparian vegetation or phreatophytes that have little commercial value but considerable significance for recreation and watershed use. Mean annual precipitation ranges between 8 inches at lower elevations and 16 inches at higher ones. Maximum rainfall intensities are high, but their

frequency is low; 24-hour rainfall at a 10-year frequency ranges from 1.5 to 4.0 inches for most of the region and up to 12 inches in southern California. The mean annual streamflow for large watersheds is only 0.5 to 2.5 inches, the lowest of the six regions. The potential for management of the seven major vegetation zones in Arizona has been reviewed and summarized by Ffolliott and Thorud (1975).

Water yield—Water yield from chaparral may be increased by clearcutting, burning or treating with herbicide, then replacing the chaparral with grass. The lack of protection by natural ground cover requires the substitution of vegetation to prevent excess erosion. Though regional potential increases are estimated to be only 1 inch or less (*table 14*), recent studies suggest possibility of much greater returns on some areas: for example, 3 to 14 inches in Arizona, depending on annual rainfall (Rich and Thompson 1974); 3 inches for grass-covered areas in southern California (Bentley 1967).

High values for water make high conversion costs justifiable. If annual water yield is increased by 3 inches, with water valued at $50 per acre-foot and with low annual operating costs, an initial cost of more than $100 per acre for converting California chaparral to grass would be justified. Typical costs per acre for converting chaparral to grass range roughly between a minimum of $25 per acre and a maximum of $80 (Bentley 1967).

Costs have been somewhat lower in Arizona. Prescribed burning of 3,000 acres of chaparral on the Tonto National Forest in Arizona cost $10 per acre with subsequent herbicide spraying at $20 per acre. The increase in water yield (1.6 inches), increased forage growth, and reduced fire hazard had an estimated total value over a 10-year period of $97 per acre, or a benefit-cost ratio of about 3 to 1. The estimated value of forage, $60 per acre, was about twice the total cost, $30 per acre (Suhr 1967). A 1974 analysis of the economics of conversion of 104,000 acres in the Salt-Verde Basin in Arizona (T.C. Brown and others 1974) indicated an expected increase in basin runoff of 2.5 percent, in cattle carrying capacity by 3.6 percent, and a decrease in fire-fighting costs by 3 percent, for a net annual return of $2.51 per converted acre.

Both in southern California and in Arizona the area covered by chaparral that is suitable for conversion to grass is limited by shallow soils and steep sloping land. Bentley (1961) estimated 9 percent for the San Gabriel Mountain chaparral; T.C. Brown (1974) estimated 21 percent of Arizona chaparral was suitable.

Peak flows—Floods are a major problem in the chaparral of southern California, where fires have often triggered disastrous, debris-laden discharges. The flood threat persists until cover is reestablished, and peak flows remain greater for 10 years or more after a fire. Complete recovery of plant cover may take 40 years.

Flood control is tied closely to fire control, which should include, where possible, the conversion of highly inflammable chaparral to a grass cover or to a less flammable condition by reducing its age and favoring more fire-resistant species. Typically, these measures are effective where the flood potential is low; elsewhere, mechanical control by debris dams and channelizing is needed for control of flood waters and the entrained sediments.

Sedimentation—The mean annual sedimentation rate is 6,400 p/m or 2,300 tons per square mile with a runoff of 5 inches.

Burning brushlands in southern California increases sedimentation enormously, but fire control alone will not prevent it. For instance, Anderson (1949b) estimated that average annual sedimentation was 600 to 9,970 cubic yards per square mile with a then-current annual burn of 0.6 to 3.2 percent; after a proposed fire control program reduced annual burns to 0.2 percent, he estimated the sediment yield would range from 516 to 8,280 cubic yards per square mile.

There seems to be no successful method for stopping erosion after wildfire in southern California. The several methods that have been tried (see "Southern California and Arizona Chaparral") are either limited in effectiveness or are quite expensive.

Success has been reported in Arizona, where mechanical erosion control was combined with seeding of lovegrasses on four small watersheds from which chaparral had been grubbed and used as a mulch; this process reduced sediment rates from untreated chaparral of about 2,000 to 5,000 tons per square mile per year to 16 to 31 tons (Rich 1961). Conversion of chaparral to grass on slopes steeper than 60 percent or on especially unstable soils is not recommended (Hibbert and others 1974).

Erosion control has been more successful in northern and central California than in southern California. Seeding grasses on three burned-over

chaparral watersheds reduced erosion rates per acre from 2.2 to 1.1 ton, from 1.7 to 0.5 ton, and from 1.5 to 0.4 ton—less than the erosion from the original chaparral cover (Burgy 1958). As in the southern California conversion, some of these areas subsequently have been subject to severe slope instability, indicated by massive land slides.[11] Steep forest and brushlands that have been converted to grass were found to be a principal source of increased sedmimentation (Wallis and Anderson 1965).

V - TOMORROW'S FORESTRY AND WATER

The study of forestry and its effects on water yield, floods, and water quality has led to three convictions:

(1) Substantial increases in water yield are attainable by creating openings in forests
(2) The undisturbed forest provides the maximum storage for flood-producing precipitation and the maximum soil stability
(3) With care in logging, timber can be harvested from many forests without unduly increasing sediment in streams, water temperature, and water chemical content.

Tomorrow presumably will see these general convictions translated, as necesary, into forest operations as one means of meeting society's demands for water, sufficient in amount and of required quality, with minimum damage in delivery. However, implementing of these ideas will not exhaust the potential of forestry to control water: current research points toward other interesting possibilities.

Water Yield

Now that increased water yield resulting from forest cutting has been achieved and demonstrated at many places, refinements of research are in order to answer such questions as: Where and by what techniques will cutting produce the greatest or most economical yield of water? Can antitranspirants be used to provide seasonal increases without cutting? How does water yield interact with management for recreation? What is the most effective role of the forest in providing needed increases in water yield? This last question also involves comparative costs and benefits.

Selection of Areas for Cutting

Maximum increase in water yield will result from cutting trees or removing brush that transpires at or near maximum rates and durations. Therefore, favorable locations are areas that have deep soil, riparian zones where vegetation has access to groundwater, areas that have direct drainage to channels (treat slopes adjacent to channels, or cut strips perpendicular to contours), and areas where streamflow per unit of precipitation is least (dense forest, sites that receive the most heat energy, and sites subject to frequent drying). A caution: losses from direct evaporation are likely to be high on exposed south-facing slopes and may partially offset reductions in transpiration when openings in the forest are created there.

Hewlett (1961) demonstrated that the base flow of Coweeta's mountain watersheds derives from soil-water drainage; this suggests that cutting trees at the base of slopes produces more water than removing trees higher on slopes (Lynch and others 1974).

Maximum delay in yield will result from accumulating snow in shaded places and at higher elevations, perhaps by using snow fences (Martinelli 1973) and by lengthening water-flow paths as much as possible.

Antitranspirants and Antievaporants

The possibilities of spraying chemicals on the forest canopy to reduce transpiration (and thereby increase streamflow) by forming a film over the leaves, by increasing their reflectivity, or by closing stomata have recently been studied. No great success has been reported. A first estimate was that evaporation from a closed canopy could be reduced by about one-sixth by cutting the width of stomata in half (Waggoner and Zelitch 1965). Later, reductions up to 15 percent in annual

[11] R. H. Burgy and Z. G. Parazifirou. 1971. Effect of vegetation management on slope stability. (Unpublished report on file, Dep. Water Sci., Univ. Calif., Davis.)

evapotranspiration were found with jack pine grown in lysimeters and sprayed with phenylmercuric acetate (Waggoner 1967). However, since mercury compounds, such as the one applied by Waggoner, pose a serious environmental problem, they cannot be used over large areas. Spraying 70 acres of hardwoods at the Coweeta Hydrologic Laboratory proved dissappointing: streamflow did not increase, apparently because the spray did not reach the stomata-bearing undersides of the leaves. Spraying aspen in Utah produced a better coverage of spray so that the width of the stomata and velocity of sap were reduced by about half; however, this spraying saved only about 1/2 inch of soil water (Hart and others 1969). Spraying red pine plantations in Connecticut saved more than 1 inch of soil moisture (Turner 1968). Anderson and Krieth (1975) report a 50 percent reduction of transpiration by using film-forming commercial antitranspirants; plants showed no apparent injury.

Davenport and others (1969), in reviewing the potential of antitranspirants, noted that they would be most effective when resistance to the passage of water from roots to leaf surface is minimal, when stomata-bearing surfaces are well covered, when new foliar growth following treatment is minimal, and when optimum rates of concentration and application are used. If and when successful antitranspirants are developed and these conditions met, this treatment, combined with cloud seeding, could increase runoff by more than the sum of the increases from the separate treatments (Satterlund 1969).

Antievaporants have been applied to the soil under forest vegetation to reduce summer losses of soil-water. The results of different trials have differed widely. In contrast, the application of antievaporants to snow surfaces has been consistently effective. In the first tests of the use of hexadecanol on brushfields and red fir forests in California, the only significant reductions in the next summer's evapotranspiration were in the bulldozed brushfields and in areas where there had been heavy applications under snow (680 pounds per acre). However, evaporation from snow was reduced by the application of hexadecanol (12 pounds per acre) to the snow surface (Anderson and others 1963). One application may be enough to last throughout the spring melt season (Smith and Halverson 1971). This treatment indicated possible saving of nearly 2 inches of water from open areas in the forest.

Recreation Use and Environmental Quality

Recreational use and environmental quality of forests are receiving progressively increased attention. Recognition of their importance will dictate modifications in forest management for water yield as well as for other purposes. The effects of management practices on water quality, visual appeal, fish and wildlife, and habitat, and other values must be considered and evaluated. Allee and Smith (1974) have graphically reported devastating results to stream environment in the Olympic Peninsula when forest management operations failed to consider these associated values adequately.

Cutting practices will increasingly be modified to leave forests that are pleasing to the eye as well as effective in producing timber and water (Litton 1968, Baker 1975). Setting aside special areas for wilderness, scenic river, wild areas, parks, and historic sites (as well as providing more areas for normal camping, picnicking, and hiking) will make special demands on water supply and pose new problems in water quality. Special treatments of forests may be required to satisfy the objectives of forest recreation.

Comparison with Alternatives

There is no question that water yield can be increased substantially by clearcutting selected forest areas or that the cost of this added water is less than that of other methods now deemed practical. Producing water by managing vegetation costs less than distilling sea water, transmitting water, or harvesting water. And the energy required to convert salt water and to pump water in transmission projects may reduce the feasibility of these alternatives as concern over limited energy supplies increases.

Cloud seeding may prove to be the cheapest source of additional water wherever it is successful. Kriege (1969) reported a 13-percent increase in annual rainfall over 12 years in the Santa Clara Valley of California, at a cost of less than 40 cents per acre-foot ($4 per acre-foot if one estimates that only 10 percent of the increase is salvageable). Hurley (1968) estimated that a $25 million cloud-seeding research program would make it possible to increase winter precipitation over the Upper Colorado Basin by 15 percent by the mid-1970's at a cost of water increases of $1.00 to $1.50 per acre-foot.

Cloud seeding over forested watersheds that have been cut to increase water yield may produce more water than the sum of the increases obtained by the two methods used independently (Satterlund 1969, Leaf 1975b). Cloud seeding and forestry are also related in another way: Cooper and Jolly (1970) have reviewed the possible ecological effects on forests of weather modification, and Ives and others (1970) have discussed programs to evaluate the environmental impacts of cloud seeding in the Upper Colorado Basin forests.

Potential Role of the Forest

The Water Resources Council (1968) has predicted that by the year 2020 consumptive use of water in the East will have increased by about 30 million acre-feet annually, and in the West by 40 million. Potential increases of water yield from forest land could satisfy perhaps one-half or more of these increased needs.

Planning reservoir design and operation together with treatment of forest land to increase water yield can make both more effective (Hawkins 1969); the amount can be increased and the quality of water improved.

Timber harvest designed to increase water yield seems to offer a comparatively economical means for producing at least part of the volume of water needed to satisfy increasing demands.

Drought periods provide special opportunities for forest management for water yield. Where water in the soil may be saved by removing vegetation, the planned conversion of brushfields to forest might well be timed to coincide with critical drought periods; in this way, the saving in water incidental to brush removal might help to offset costs of reforestation. The temporal and spatial sequence of conversion might thus achieve maximum returns for the present and create future forests to meet both timber and water-yield objectives (Anderson 1966). The extension of forests into some areas now occupied by alpine flora may be feasible by techniques that were developed for the Alps (Aulitzky 1967). The use of trees to shade artificial glaciers or deliberately avalanched snow accumulations may make these techniques more effective in prolonging low season streamflow (National Academy of Sciences 1971). Martinelli (1973 and 1975) has discussed use of snow fences and other techniques to prolong water yield in alpine areas.

Flood Prevention

Tomorrow's forestry may contribute to flood prevention in three ways: 1) by acknowledging the flood-preventing role of the forest, 2) by enhancing that role by protection and reforestation, and 3) by pursuing imaginative research to strengthen this role.

Forest Role

Foresters should accept the forest as the best natural cover for preventing floods when it is protected from overgrazing, severe fire, or by denudation by insects or disease. Present-day fire control and restriction of grazing pretty well assure that most forest areas meet flood prevention criteria fairly well except the chaparral of the Southwest, with its peculiar climate and unusually high fire hazard. Certainly the recent extremely large fires in the Pacific Northwest are cause for concern also.

The forest can prevent excessive acceleration of floods under sustained-yield timber management. Flood-producing rainstorms, overland flow, and streamflow are controlled about equally well by sapling, pole, and sawtimber stands. One important key to flood prevention is continued maintenance of an undisturbed forest floor over most of the area. Where disturbance is necessary to enable forest harvesting, it should be held to a minimum; and overland flow should be controlled by proper location, construction, and maintenance of roads, trails, and landings, and by special techniques designed to offset adverse effects. Where snowmelt contributes to floods, special techniques can hold flood-water discharges from watersheds to a minimum.

Protection and Reforestation

The forester's flood-prevention function is twofold: protection and reforestation. Protection from fire, overgrazing, and destructive logging is closely associated with timber production and recreational use as well as with water production. No further justification of protection is required. We reiterate that the occasional, superficial ground fire has little effect on forest soil and water; only repeated fires or high-intensity fires that completely consume the forest floor will damage it seriously. Grazing is another matter; relying on the forest alone as a source of forage can destroy both feed

and feeder. Further care in logging, especially in the location and design of logging roads, will be required in future forest protection.

Perhaps the most productive action in forest flood prevention and control is the afforestation of idle, abandoned lands that are sources of overland flow and sediment. Of the 35 million acres of unused plantable land, top priority in forestation should be given to those unforested areas that are truly sources of present or future flood and sediment damages. The nature and expected extent of such damages need to be better assessed.

Research

Research to devise practices that will improve flood prevention should be centered on the three major components of forest floods: local surface flow, subsurface flow, and snowmelt. The first involves control of runoff from such impervious surfaces as roads, landings, and skid trails. The second involves determining the possibility of slowing down subsurface flow by temporary storage, utilizing incompletely filled soil-detention storage, or by developing access to underground storage beneath subsurface flow planes. Capitalizing on this available storage capacity may involve combining surface forest with subsoiling, using explosives underground, or digging wells. No systematic research on soil engineering for modifying soil-water storage has been reported, but such research was recommended in a National Academy of Sciences (1971) report. Discovery and use of those strategic areas that can hold the key to flood prevention through desynchronization of flow is also involved.

To manage the snowpack to prevent floods produced by rain on snow and spring snowmelt, we need to develop procedures that permit accurate prediction of snowpack contributions to floods based on the size of the pack, the meteorological factors, and the interactions between them and aspect, slope, elevation, and vegetation patterns. Second, means of hastening or slowing snowmelt should be studied further. These would involve reforestation, various kinds of cutting on strategic areas, and sowing from the air of chemical substances that alter snowmelt.

Erosion—Sedimentation —Water Quality

Tomorrow's control techniques will probably include greater attention to erosion control and greater use of the forest to improve water quality. Use of the dilution potential obtained by increased water yield, possibly with the aid of detention structures or controlled snowmelt, should be studied further. The effect of forest cover and its management on the biology and chemistry of water bodies must be better understood.

Erosion control is easier when surface disturbance has been held to the minimum by use of overhead logging systems—whether balloon, helicopter, or skyline systems. Faster logging by more use of improved equipment can also reduce the exposure time for disturbed areas and permit earlier installation of control measures.

The future use of forestry to increase water yield and control floods and erosion will depend on the imaginative wedding of insights offered by research to the ever-growing battery of techniques and equipment for inventory and computations. These may be illustrated by some speculations bearing on management of snow basins (Anderson 1966):

> Inventory techniques around the corner include machine interpretation of aerial photos, including such simple inventory characteristics as forest species, densities, and tree heights, but also including special characteristics such as radiation, extent of snow cover, and snow volumes (as in cornices). Instruments for aerial appraisal of the depth and densities of the soil and fractured rock mantle in mountain watersheds hold promise of becoming available . . .
>
> Snow physics research will give a basis for prediction of snow and snow water behavior. The alternative is "cut and try tests" on the some 6,000 different "forest sites" of the West. Further understanding of heat and water budgets, together with knowledge of surface winds and turbulence, may serve to explain the extreme variation in snow accumulation, snowmelt, and evapotranspiration loss. Such explanations will inevitably lead to better designed management techniques and reduction in the number of experimental tests that need to be made of alternative techniques.
>
> Some testing of management techniques by controlled experiments may quite possibly be accomplished largely by finding and evaluating analogous situations in nature. Interactions of forests and terrain seem to be suited to such testing by selection. Other

experimental testing obviously involves laboratory and field tests. Methods of control of the melting of snow, such as by albedo control, need further development. Control of evaporation and condensation of snow by chemicals, such as the long-chain alcohols, should be pursued. Further tests of control of snow drifting, of piling snow by avalanche initiation, and of creation of artificial glaciers might be considered. The soil-water "reservoir" is practically uninvestigated from the viewpoint of management of its characteristics, except by simple resorting to vegetation removal and type conversion. Sterilization of the deeper soil layer to prevent root penetration and transpiration losses seems possible.

The prospects for management of forests for water are bright. Goodell (1965) has set for the proper goal:

> The culture of the forest so that there is no water wasted by plant material that is neither economically important, necessary to the protection of the soil or of water quality, nor necessary to the production of wood of desired specifications.

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The Pacific Southwest Forest and Range Experiment Station

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GPO ☆ 789—5

COMPUTER EVALUATION OF EXISTING AND PROPOSED FIRE LOOKOUTS

Romain M. Mees

Traditionally, the location of fire lookouts is determined by fire history and the areas where fires have been spotted. Fire managers consider the spatial concentration of past fires in an area, and judge the relative portions of an area that a lookout can "see." This procedure for evaluating existing lookouts can be time consuming, and is highly subjective. And the evaluation of potential alternative fire detection sites can require two or three times as much effort as that needed for existing lookout stations (U.S. Forest Service 1971).

This report describes a computer simulation model for evaluating existing lookouts so that alternate locations and detection by aircraft or cooperating agencies can be assessed. The model was tested by using data from the Sequoia National Forest, California. The model is applicable on a forest and regional basis. Its use can contribute toward a uniform interpretation and application of procedures for evaluating fixed lookouts. The primary value of the model is to rank lookouts on a common objective basis. The ability to generate visible seen areas should enable fire managers to consider quickly more efficient flight routes into unseen areas of the lookouts for aircraft detection. Copies of the computer programs are available upon request from the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701, Attention: Computer Services Librarian.

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REPORT PSW- 19/1976

Mees, Romain M.
1976. **Computer evaluation of existing and proposed fire lookouts.** USDA Forest Serv. Gen. Tech. Rep. PSW-19, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A computer simulation model has been developed for evaluating the fire detection capabilities of existing and proposed lookout stations. The model uses coordinate location of fires and lookouts, tower elevation, and topographic data to judge location of stations, and to determine where a fire can be seen. The model was tested by comparing it with manual detection on a National Forest in California. By using this simulation technique, planners can rank lookouts on a common objective basis, and will be able to plan more efficient flight routes into unseen areas of a lookout for detecting fires by aircraft.

Oxford: 432.21–069:U681.3
Retrieval Terms: lookout stations; fire management; simulation; computer programs.

DATA REQUIRED

The following data are needed in using the model:

1. The longitude and latitude coordinates (degrees, minutes, seconds) of all lightning and man-caused fires for a given number of years. The coordinates can usually be obtained by digitizing existing fire-occurrence maps or by using existing U.S. Forest Service Fire Report forms.
2. The longitude and latitude coordinates of each lookout. These must be specified as accurately as possible (degrees, minutes, seconds, fractions of a second).
3. The elevation of each lookout, i.e., the sum of tower height and the elevation at the lookout position.
4. Elevation data described on a grid system for the area covered by the lookouts. One source of elevation data is TOPOCOM (digital terrain data), available on a 208.333-ft. grid for the continental United States (U.S. Army 1973). However, these data should be carefully checked against existing topographic maps before they are used. For technical information concerning the elevation data, contact the U.S. Geological Survey, User Services, 507 National Center, Reston, Virginia 22092.

The acquisition of data requires a substantial amount of effort and some cost. However, most of the data need to be collected only once and can have substantial uses in other types of planning work.

DETECTION PROGRAM

Lookouts are evaluated on the basis of intersecting geometries between seen areas of the lookout and fire intensity areas of the planning unit (*fig. 1*). The intensity factor for each of these areas is computed

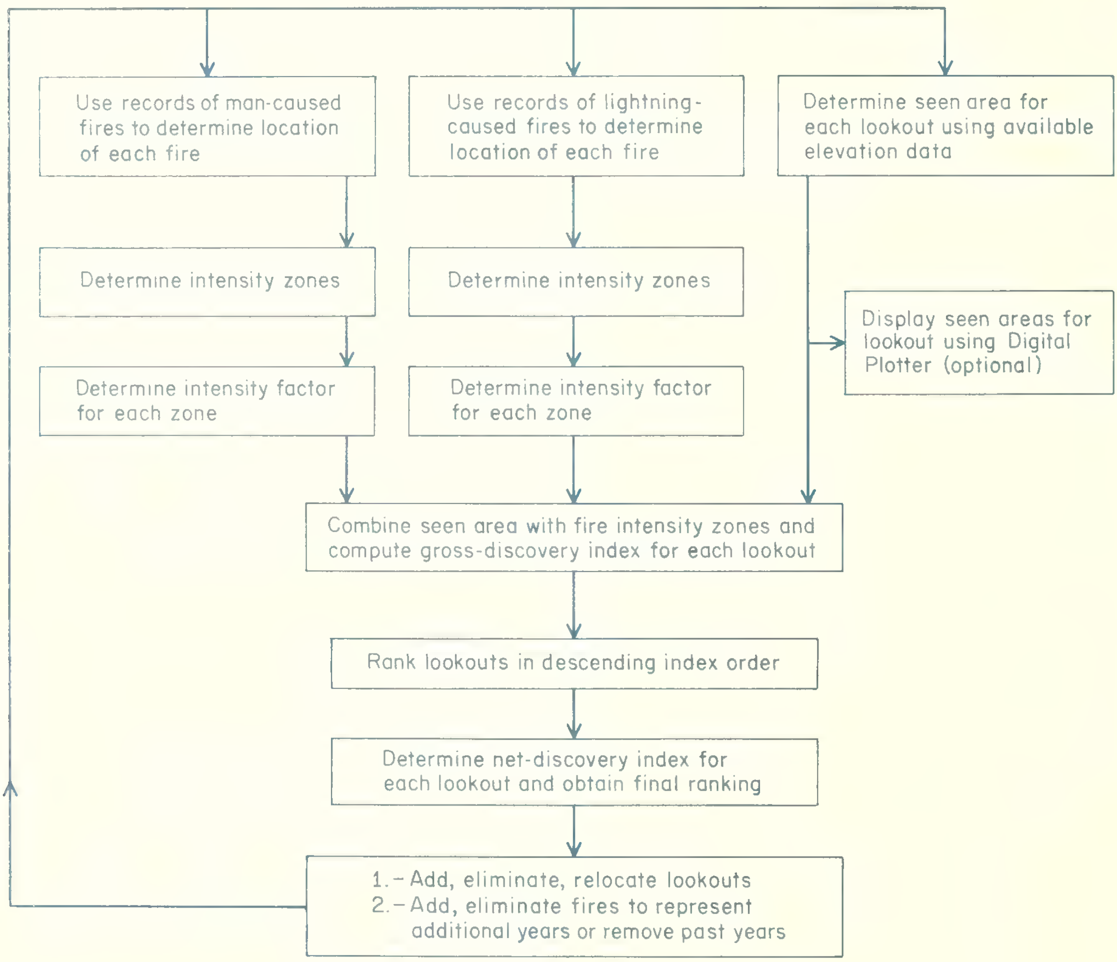

Figure 1—The evaluation and ranking of fire lookouts are functions of seen areas and fire-intensity zones.

by

$$I_a = 1000 \times \frac{\text{Number of fires}}{\text{Number of acres}}$$

in which the coefficient 1000 is used as a scaling factor to improve computational accuracy.

The area of interest can be divided into a square mile grid so that each fire falls into one of the squares (*fig. 2*). The total acreage associated with each intensity area will, therefore, be an exact multiple of the area of the basic square.

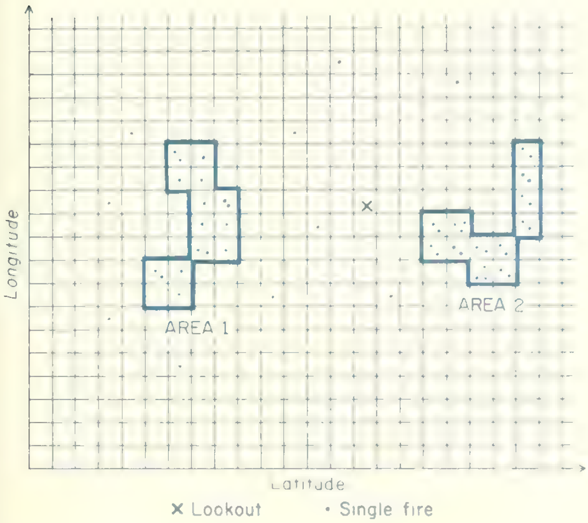

Figure 2—These two fire-intensity areas have a minimum of three fire starts within each area. Each square represents 1 square mile, and each dot a single fire.

The evaluation of fire intensity areas and associated fire-start counts within each seen area ignores the local effects of weather, visibility, existing fuels, and fuel conditions which existed at the time of each specific fire. Therefore, it is important that an adequate number of fire occurrences be considered. This consideration will tend to average out local conditions over a long period of time and will result in a reasonable estimate of the value of a lookout usually designed to last many years.

The following procedure demonstrates how the program works: select a square with at least one fire start in it, examine its eight neighboring squares (nine squares make up a neighborhood in this case), and check if any of these squares contain at least one fire start. Continue the process until all neighboring squares which contain at least one fire are exhausted.

In *Figure 2*, area number 1 has intensity

$$I_a = 1000 * \frac{17}{14 \quad * \quad 640} = 1.8973$$

and area number 2 has intensity

$$I_a = 1000 * \frac{26}{12 \quad * \quad 640} = 3.3854$$

Each square having two or more fire starts is absorbed into the intensity area where each square must contain at least two or more fire starts (area number 2, *fig. 2*). This condition allows the setup of high intensity areas by the program. Furthermore, a neighborhood can be defined as the aggregation of squares within a 2, 3, 4, . . ., mile vertical and horizontal distance of the initial square. The requirement that each intensity area must contain a minimum of fire starts has been included.

The computer program can be directed to create a basic square grid, sort the fire starts as to location, and create the intensity areas. If a fire in a given square has no neighbor, it becomes a single fire with an individually assigned area of 1000 acres and intensity constant $I_a = 1$. If an intensity area contains less than the required minimum number of fires per area, all fires involved will be considered single fires.

The program has been set up so that the user can specify the minimum number of fires (NMIN) per unit square to delineate the high-intensity areas. These areas will be established first followed by the areas in which each square contains 1, 2, 3, . . ., NMIN fires.

With the intensity areas established, the program accumulates the intensity areas of like intensity into five possible fire intensity zones.

The overall fire intensity for each zone is computed by:

$$I_i = 1000 * \frac{\Sigma \text{ No. of fires in area i}}{\Sigma \text{ Acreage in area i}}$$

in which each intensity area belongs to one of these zones:

1 if $I_a < 0.1$
2 if $0.1 \leq I_a < 1$
3 if $1 < I_a \leq 3$
4 if $3 < I_a \leq 10$
5 if $10 < I_a$

The model develops the seen areas by using the position and height of each lookout and the elevation data provided. The model was tested by using data from the Sequoia National Forest and TOPOCOM elevation data. Any efficient line of sight computer

subroutine can be used to generate the seen areas based on the available elevation data. Use of the program as described here, however, is recommended. The program was designed to handle large amounts of elevation data efficiently at reasonable cost of machine time and computer core and storage costs. Another advantage of this program is that the seen areas generated to evaluate the lookouts are permanently recorded on existing computer storage devices and can be displayed by means of a plotting device at the users convenience.

To evaluate each lookout independently, the model estimates the area overlap between each zone and the seen area for the lookout. It sums all squares (1 square mile) partially or completely in the seen area of a lookout and computes the gross-discovery index. This index is the sum of total acreage seen multiplied by the intensity factor (number of fires/acre) of each zone. The equation is . . .

$$G_d = \Sigma \text{ (acreage per unit square) } * I_z$$

in which I_z is the appropriate zone-intensity index for each square.

To establish the relative value of each lookout, the program lists the lookouts in decreasing order as to gross-discovery index. The highest ranking lookout is left at full value.

The net-discovery index for the second-ranked lookout is computed with any seen area already covered by the first lookout removed. The net-discovery index, then, is the sum of total acreage seen (and not covered by higher-ranking lookouts) multiplied by the intensity factor (number of fires per acre) of each zone. The remaining lookouts are evaluated in a similar fashion with overlapping seen-areas credited to the higher ranking lookouts.

The model developed gross-discovery indexes (*table 1*) by using data on fire occurrences (man-caused and lightning) from 1960-1967, the TOPOCOM elevation data, and the elevation and position of 11 lookouts on the Sequoia National Forest. The gross-discovery index, the number of fires in each seen area, and the acreage for each intensity zone were developed for both lightning and man-caused fires.

Table 1—*Acreage in each of five fire-intensity zones (I_z), number of fires in each seen area and the gross discovery index*[1] *for lightning and man-caused fires, by lookout*

Lookout	Name	Fire intensity zones (acres)					Fire incidence	Gross discovery index
		$I_z \leq 0.1$	$I_z \leq 1$	$I_z \leq 3$	$I_z \leq 10$	$I_z > 10$		
				Lightning fires				
1	Baker	0.	1000.	11520.	4480.	0.	36	37.
2	Jordan	0.	0.	21120.	16000.	0.	93	96.
3	Needles	0.	0.	21120.	18560.	0.	102	106.
4	Buck Rock	0.	0.	11520.	4480.	0.	45	36.
5	Bald Mtn.	0.	0.	26240.	17920.	0.	112	112.
6	Mule Pk.	0.	0.	16000.	6400.	0.	48	51.
7	Tobias	0.	1000.	21120.	3200.	0.	54	47.
8	Oak Flat	0.	0.	9600.	0.	0.	17	15.
9	Blue Mtn.	0.	0.	7040.	640.	0.	16	14.
10	Delilah	0.	0.	640.	1280.	0.	5	6.
11	Breckrdg.	0.	0.	8960.	2560.	0.	24	24.
				Man-caused fires				
1	Baker	0.	0.	10240.	3840.	0.	38	35.
2	Jordan	0.	1000.	8960.	0.	0.	17	17.
3	Needles	0.	3000.	7040.	640.	0.	20	18.
4	Buck Rock	0.	1000.	4480.	640.	0.	16	12.
5	Bald Mtn.	0.	2000.	3200.	0.	0.	7	8.
6	Mule Pk.	0.	0.	1280.	1280.	0.	6	8.
7	Tobias	0.	0.	8960.	1280.	0.	31	22.
8	Oak Flat	0.	2000.	3840.	2560.	0.	17	20.
9	Blue Mtn.	0.	0.	4480.	640.	0.	13	11.
10	Delilah	0.	1000.	2560.	0.	0.	6	6.
11	Breckrdg.	0.	0.	1280.	0.	0.	2	2.

[1] Sum of the total acreage seen multiplied by the fire intensity factor (number of fires/acre) of each zone.

Table 2–*Acreage in each of the fire intensity zones (I_Z), total acreages within each seen area, net discovery index*[1] *for man-caused and lightning fires, by lookout*

Lookout	Name	Fire Intensity Zones (acres)					Total	Net discovery index
		$I_Z \leq 0.1$	$I_Z \leq 1.$	$I_Z \leq 3$	$I_Z \leq 10$	$I_Z > 10$		
					Lightning fires			
3	Needles	0.	0.	21120.	18560.	0.	39680.	119.
5	Bald Mtn.	0.	0.	24320.	17920.	0.	42240.	122.
2	Jordan	0.	0.	17920.	11520.	0.	29440.	83.
1	Baker	0.	0.	10240.	4480.	0.	14720.	38.
7	Tobias	0.	0.	14720.	1280.	0.	16000.	32.
6	Mule Pk.	0.	0.	5120.	4480.	0.	9600.	29.
4	Buck Rock	0.	0.	16000.	0.	0.	16000.	28.
8	Oak Flat	0.	0.	9600.	0.	0.	9600.	17.
11	Breckrdg.	0.	0.	6400.	2560.	0.	8960.	23.
9	Blue Mtn.	0.	0.	3840.	0.	0.	3840.	7.
10	Delilah	0.	0.	1920.	0.	0.	1920.	3.
					Man-caused fires			
3	Needles	0.	3000.	7040.	640.	0.	10680.	18.
5	Bald Mtn.	0.	2000.	3200.	0.	0.	5200.	8.
2	Jordan	0.	1000.	7040.	0.	0.	8040.	14.
1	Baker	0.	0.	8320.	3840.	0.	12160.	32.
7	Tobias	0.	0.	5760.	1280.	0.	7040.	16.
6	Mule Pk.	0.	0.	0.	1280.	0.	1280.	6.
4	Buck Rock	0.	1000.	4480.	640.	0.	6120.	12.
8	Oak Flat	0.	2000.	3840.	2560.	0.	8400.	20.
11	Breckrdg.	0.	0.	640.	0.	0.	640.	1.
9	Blue Mtn.	0.	0.	3200.	640.	0.	3840.	9.
10	Delilah	0.	1000.	2560.	0.	0.	3560.	6.

[1] Sum of total acreage seen (and not covered by higher-ranking lookouts) multiplied by the fire intensity factor (number of fires/acre) of each zone.

SAMPLE PROBLEM

The net discovery index and net acreage within each seen area are shown for both man-caused and lightning fires in *table 2.*

The sum of the net-discovery indexes for lightning and man-caused fires are shown in *table 3.* Columns 1 and 2 show the results of the computerized method and the Sequoia National Forest work respectively. The third column shows the actual number of fires within a 15-mile radius of each lookout.

If we assume a net discovery index of 50 as a cutoff value (U.S. Forest Service 1971) for acceptable lookouts, we need to consider eliminating two additional lookouts. The evaluation of the Tobias lookout by the Sequoia National Forest included 180,000 acres of low intensity acreage in the seen area of the Tobias lookout. Inclusion of this amount of acreage on the basis of 345 fires within the 15-mile radius and 85 fires within its seen area is subjective and tends to overcredit lookouts. Further differences in net discovery indexes between the two methods can be attributed to the seen areas, definition of intensity zones, and computational techniques.

One program option is the visual display of seen areas by means of a digital plotter. The seen area generated for the Baker Mountain lookout by the program is compared to the seen area used by the Sequoia National Forest for the Baker mountain lookout (*fig. 3*).

The difference in seen areas in the comparison may be due to both the difference in methods used to generate the seen area and the accuracy of the data used. Any seen area generated by an office procedure or a computer should be carefully checked out in the field for accuracy. Any method used to generate seen areas will present unique problems and differences in actual seen areas generated from other existing procedures.

The purpose of the model is to facilitate fire

Table 3–*Net discovery index*[1] *values obtained by computer and manual analyses, and number of fires within 15 miles of each lookout*

Lookout	Computer analysis	Manual analysis by the Sequoia National Forest	Fires within 15-mile radius
Needles	137	135	612
Bald Mountain	130	127	487
Jordan	97	76	451
Baker	70	80	417
Tobias	48	136	345
Buck Rock	40	65	211
Oak Flat	37	18	426
Mule Peak	35	18	426
Breckenridge	24	23	149
Blue Mountain	16	14	164
Delilah	9	14	117

[1] Sum of total acreage seen (and not covered by higher-ranking lookouts) multiplied by the fire intensity factor (number of fires/acre) of each zone.

Figure 3–A comparison shows the seen area (parallel vertical lines) generated by computer for the Baker Mountain forest fire lookout, and the seen areas (solid lines) used by the Sequoia National Forest for lookout.

detection *planning* and to generate a relative ranking of lookouts by using the geometry of the seen areas and intensity zones. In long-range fixed detection and aerial detection planning, a small consistent percentage error in seen areas will have an insignificant effect.

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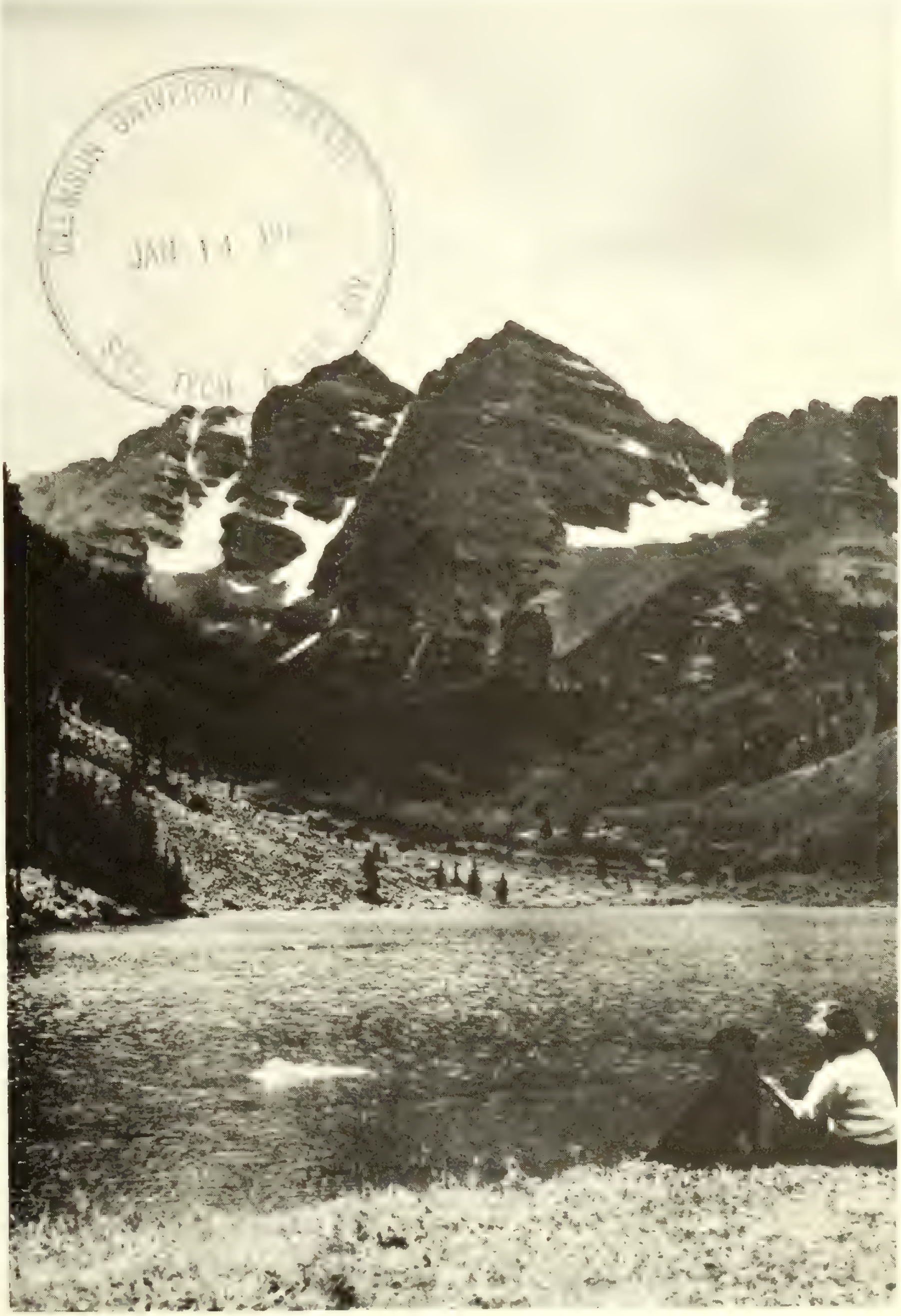
STATE-OF-THE-ART METHODS for research, planning, and determining the benefits of outdoor recreation



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GENERAL TECHNICAL
REPORT PSW-20 /1977

STATE-OF-THE-ART METHODS
for research, planning, and determining the benefits of outdoor recreation

Gary H. Elsner, Compiler

CONTENTS

Elsner, Gary H., compiler.
1977. State-of-the-art methods for research, planning, and determining the benefits of outdoor recreation. USDA Forest Serv. Gen. Tech. Rep. PSW-20, 62 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

These eight papers were presented at Working Party S6.01-3, XVIth World Congress of the International Union of Forestry Research Organizations, Oslo, Norway, June 22, 1976. Topics covered include (a) improving studies on demand for outdoor recreation, (b) forecasting changes in number of visitors after a change in recreational quality at an area, (c) comparing the use of site surveys with home interviews for recreation planning, (d) measuring the relative value of selected outdoor recreation activity areas, (e) modeling changes in use or area conditions to determine effects on use patterns and encounters between visitor groups, (f) surveying wildlife-related recreation to determine impact on a local economy, (g) applying mathematical programing in the context of planning for multiple goals, and (h) investigating the degree of aforestation preferred for different broad categories of land uses in recreational areas.

Oxford: 907.2
Retrieval Terms: outdoor recreation; forest recreation; recreation area planning.

Compiler

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PREFACE

The challenge of planning for outdoor :ation is shared by many countries ighout the world. This publication offers ection of state-of-the-art papers by au-, from several countries which are active-aling with this challenge. The eight s were prepared for the International of Forestry Research Organizations RO) XVI World Congress, held in Oslo, y, June 20-July 2, 1976. They are the l discussion papers for IUFRO Working , S6.01-3, Methodologies for Research, ning, and Determination of Benefits of oor Recreation, which met on June 22.

The lead paper by H. N. Van Lier sets the e for the papers that follow by describing demand modeling approaches, explaining r strengths and weaknesses relating to ning needs, and making several suggestions improvements including the need to study epth the separate influence of the three c system components--origin, destination, linkage--and the need to adequately model titutability. The next paper, by Peter g, investigates in some detail the desti-on element and the question of substituta-ty. The paper explains and illustrates simple numerical examples for ski areas a l for forecasting the short-term change in er of visitors to an area which result a change in the destination's quality.

Mordechai Shechter's paper compares in e detail two approaches to estimating out-recreation use and benefit information. he basis of two comprehensive studies of largest national park in Israel, he con-es that site surveys are often more effi-t and cheaper than home interviews. How-, the paper recommends comprehensive home eys at longer intervals, say every 10 s, for the collection of additional data for broad area planning.

Joseph E. Hoffman's paper illustrates the of two measures of the value/cost ratio in aring the perceived value with the devel-nt and management costs for several alter-ve outdoor recreation activity areas. His indicate that areas with low development s may have a higher value/cost ratio than ally expected.

The report by Robert C. Lucas and Morde-Shechter describes an important and prac-l model for simulating changes in manage-policy or access within dispersed outdoor eation areas. The model predicts the effects upon use patterns and encounters between visitor groups. It was developed to help explain and predict use patterns and encounters within U.S. Wilderness areas where solitude is often a prime objective, and, consequently where management would often like to decrease encounters. However, this same model may be useful in examining alternative management strategies in areas where management may wish to increase encounters, e.g., in parks where wildlife observations are important and where such an event may be termed an encounter. The approach may indeed by appropriate for simulating a wide range of management alternatives in a wide array of dispersed outdoor recreation systems.

Determining the relationship between hunting, fishing, nonconsumptive wildlife use and the local economy is a difficult but worthwhile task for wildlife-related recreation planning. John L. Mechler and E. Lawrence Klein report on a major study of wildlife in the southeastern United States. Their paper is instructive both in terms of the area studied and in terms of illustrating how a careful study of gross expenditures may be useful to the objective planing of wildlife-related recreation which may have a positive monetary impact on a local economy.

Long-range planning for adequate outdoor recreation areas is usually done in a context in which recreation values must be compared with other uses for the land, such as, timber production. A. B. Rudra specifies carefully the use of goal programing and explains its application to an illustrative area containing potential for recreation, timber and multiple uses. Since many of the parameters needed for either conventional linear programing or goal programing are never known with complete certainty, his paper also includes a brief introduction to the use of stochastic programing and explains its advantages.

The long-range planning of alternative uses of landscape units has received intensive investigations in Germany. Ulrich Ammer's paper highlights the results of these studies in terms of the preferred degree of aforestation. His conclusions apply to forested lands in and around populated areas and rural areas. The results are compared with the current proportions of forested lands in each category and implications for changes in planning goals are described.

These papers were prepared for an

international conference of forestry researchers. But each paper has its own relevance to a specific decisionmaking situation and as such may be useful to recreation managers or planners who are searching for a way to gain additional objectivity.

One goal of IUFRO is to increase the communication among forestry researchers worldwide. This publication was designed to help achieve that goal.

Improvement of Demand Studies as Tool For Planning Outdoor Recreation

H. N. Van Lier

Abstract--Planning for recreation sites in forested areas requires solution to the sequence of problems of determining the type, location, capacity, and layout of facilities. Models have been developed to forecast the demand for specific sites, but they are not necessarily applicable to other sites. A gravity model was developed to overcome this limitation. Alternatives in the form of competing recreation sites are included in the model. But even this kind of model has limitations: the impossibility of clearly separating three basic factors that affect the distribution of trips: origin of travel, destination, and linkage (or reaction to the distance to be traveled). In addition, the meaning of each factor has not yet been thoroughly investigated.

The demand for outdoor recreation is evident. The main problem is determining not only what size it will take, but also in what direction it will change. As Bijkerk (1975) emphasized, this demand problem also covers forest areas since "economic and social changes in the western world increase the need for multiple land use, leading to the fact that recreation in forested areas, therefore, is an important issue as well from the point of forestry policy as forestry planning." The same author points to the fact that "as a result of changing economic and social circumstances--the demand created by the happy few now being created by social groups, the addition of day and weekend recreation to that in vacations, the greater mobility of recreationists and the awakening of the urban population to the fact that the abundance in natural resources is dwindling--forests are becoming an increasingly important feature in outdoor recreation."

Planning of forests for recreation or planning of recreation in forest areas means solving the sequence of problems concerning the determination of type, location, capacity and layout of outdoor recreational facilities. Facilities in this context mean all kinds of provisions for outdoor recreation, as for instance small playgrounds, beaches, waters, large recreational areas, special projects, etc. It has often been emphasized that a close relationship exists between the components' type, allocation, capacity and layout in recreation planning (Van Lier and others 1971). Nevertheless a sequence-based approach may meet the first requirement.

Demand studies are a central issue in these problems. According to Bijkerk (1975), "adequate planning of the important phenomenon of recreation, good statistics on participation rate, distribution over types and distance, frequency and time of occurrence is vital."

Demand studies are needed in the first place for the determination of type and amount of (additional) facilities. Since in many of these demand studies models are used in which the distribution-effect of recreationists over the area is taken into account by means of distance functions, they also form a basis for the allocation problems as well as for the capacity of projects. Layout means type, size and mutual location of different elements in projects or areas. It determines the attractiveness of the total facility--a quality that affects demand. Demand studies are, therefore, vital for the planning of outdoor recreation.

HOW DID IT ALL START?

Older studies regarding outdoor recreation can be divided into two types. The first type, in which a sample of a certain population has been interviewed at home about their outdoor recreational behavior, has been carried out in several countries in the last 20 years. Information is gathered about background variables (as income, family size, age, sex, profession, etc.) on the one hand and number of trips, type of projects, distance traveled, activities performed, etc. on the other hand (Centraal Bureau voor de Statistiek 1966, Outdoor Recreation Resource Review Commission 1962, Rijksdienst voor het Nationale Plan 1961). The data are often, but not always, used for studies regarding the influence of background variables upon behavior on outdoor recreation.

The second type of research can be called project research. People visiting certain types of outdoor recreational projects are interviewed regarding their origin, the distance traveled, the activities performed on the project, the expenditures, and some background (socio-economic) variables. Based on these data, very often so-called use-models are constructed, of which the general form is:

$$V_i = f(P_i,\ D_i,\ x_1\ \ldots.\ x_n) \tag{1}$$

in which the visit to a certain project from a certain origin depends on the population (P_i), the distance (D_i) and (some) socio-economic variables ($x_1\ \ldots\ x_n$).

For example Merewitz (1966) constructed the following model for a lake in the U.S.A.:

$$V_u = e^{(2{,}4976\ -\ 1{,}894\ S_u\ +\ 0{,}0045\ S_u^{-3}\ +\ 0{,}0025\ P_u)}\ .\ P_u\ .\ D_u^{\ 0{,}7978}$$

in which population (P_u), distance (S_u) and population density (P_u . D_u) are taken into account. Van Lier (1969/70) constructed models for inland beaches in the Netherlands:

$$V = \frac{P}{200}\ .\ e^{(-0{,}08D\ +\ 2{,}5)} + \frac{0{,}05\ P}{100}$$

in which P = population and D = distance.

One of the main disadvantages of this type of model is the fact that alternative (competing) projects and areas are not explicitly taken into account (one has to bear in mind that using visit-numbers means that the influence of competing projects is implicitly accounted for). This lack in the modeling means that...

1. It is very hard to transplant a calibrated use-model to other areas, given the fact that the support-situation (types and distribution of facilities) in most cases is quite different, while it also might be that the "demand" differs.

2. The influence of a to-be-created facility or the improvement of existing ones cannot be calculated explicitly.

Aside from these limitations, most models also cannot be transplanted in time, since changes of behavior in time mostly are not taken into account. This, however, is very often true for other models also and therefore will be ignored in this paper.

For these reasons, new model-types were developed in the past 10 years. It all started with the gravity-model approach of Van Doren (1967), in which the alternatives are taken into account in the following way:

$$V_{ij} = C\ \frac{P_i\ A_j\ D_{ij}^{-b}}{\sum_{j=1}^{J} A_j\ D_{ij}^{-b}} \tag{2}$$

where the population (P_i), the attraction index (A_j), the distance between origin and project (D_{ij}) as also the combined influence of attraction and distance of the competing projects ($\Sigma_{j=1}^{J}\ A_j\ D_{ij}^{-b}$), are taken into account.

SHORTCOMINGS

The shortcomings of and problems with the use-models have already been mentioned.

In recent years, the approaches with gravity-models are also criticized by many authors. Niedercorn and Bechdolt (1969) drew distinctions between an origin factor, a destination factor, and a linkage factor as essential parts of the modeling. On the basis of these distinctions, the following shortcomings can be listed:

1. The impossibility of separating and extracting these three factors very clearly. This problem has been emphasized many times and by many authors. Both statistically and conceptually it is impossible to separate the influence of origin, destination and linkage on visit rates (or numbers) of outdoor recreational facilities. Statistically it is impossible because the values given to, for instance, the

attraction indices of projects or areas and distance parameters (as part of a specific distance function) depend to a certain degree on the statistical analyses procedure that is used (as for instance, covariance techniques, regression analyses). In this respect the criterion used as a measure for the goodness of fit plays also an important role. Conceptually the separation is difficult because it assumes that the influence of the origin, i.e., the push-factor, in no way is related with the support situation, while for the same reason the attraction-index is assumed to be unrelated to the decision of people whether they will have their outing or not.

In other words, it is assumed that the decisionmaking process regarding the making of a trip, yes or no, by an individual runs as follows: (a) first, the person decides that he definitely wants to go out no matter what he can do outdoors; (b) second, he makes an inventory of all possibilities of the projects and the travel distances and then chooses which one he will visit, knowing the properties of the different projects (attractivity) as also the barriers (i.e., distance and travel-time costs) to overcome.

There are reasons to believe that the decisionmaking process sometimes more or less runs like this, but in many cases both aspects are interwoven: many persons decide to make a trip because they know a very nice place to perform a certain wanted activity. Nevertheless the distinction in origin-, destination- and linkage-factors is useful, because it enables one to approach the process systematically. One has, however, to keep in mind that this distinction is a means, not a purpose in itself.

2. The meaning of each of these three factors has up to now not been investigated thoroughly. In other words, what are the background variables in the push-factor, how is a linkage perceived by the recreationists, and what properties of the projects determine the attractivity? Recently, studies regarding these aspects have started to appear.

RECENT DEVELOPMENTS

Regarding the Research Itself

Cesario (1975) recently proposed a new method to analyze outdoor recreation trip data (for instance, regarding visits to forest areas or projects which are situated in and closely related with these areas). In this method a two-stage approach is followed. In the first stage a covariance technique is used to extract systematically origin factors (called emissiveness) and destination factors (called attractiveness). In the second stage an analysis is carried out in order to find the influence of different factors for both the emissiveness and attractiveness. Different techniques can be used for this, as for instance, multivariate analyses, etc. For the emissiveness selected characteristics of population centers can be used. In the same way the attractiveness can be analyzed by using project characteristics.

In the approaches of analyzing trip distribution regarding outdoor recreation, Klaassen (1974) distinguishes between projects or areas which are origin-exclusive and those which are destination-exclusive. When a large part (say 70 percent) of the recreationists on a certain project originate from one population center, the project has origin-exclusivity. When the majority of all recreationists from a certain population center travel to one destination, then that project has destination-exclusivity. Studies regarding the problem of planning a large number of small areas as opposed to a small number of large areas are starting. Klaassen (1974) found that the first planning system (a large number of rather small areas) might be advantageous. According to Bijkerk (1975) the same effect seems to occur in town planning, where "polynucleation seems to be the leading principle."

It is obvious that future research regarding demand for outdoor recreational facilities should also focus on these aspects.

Regarding Demand-Modeling

Many attempts have been made to improve the structure of both use-models and gravity-type models. Regarding use-models, Van Lier (1973) constructed the following one for inland beach recreation in the Netherlands:

$$V = \left[\alpha(P-E) + \beta B\right] e^{-jD_r} (A_{c1} + A_{c2})^{-1} \qquad (3)$$

in which the population (P), the vacationists elsewhere (E), the vacationists in the area (B), the distance (D_r), the alternatives inside (A_{c1}) and outside (A_{c2}) the origin, both weighted according to recreation type and distance are taken into account.

The formula can be rewritten as follows:

$$V = \frac{[\alpha(P-E) + \beta B]\ e^{-jD_r}}{(A_{c1} + A_{c2})} = \frac{[\alpha(P-E) + \beta B]\ e^{-jD_r}}{\frac{1}{5}(\sum_{n=1}^{5} g_n c_n + \sum_{k=1}^{K} g_k r_k c_k + \sum_{m=1}^{M} g_k r_k c_k)}$$

where g = competitional effect of a certain project on other projects, c = capacity of that project and r = reduction coefficient depending on distance. This shows that properties of population centers and alternative projects explicitly also are taken into account. The model simulates trips originated in a gravitational field.

For the use of wilderness area, models were constructed by McKillop (1975) of the following type:

$$Y_{it} = b_0 + b_1 X_{1it} + b_2 X_{2it} + \ldots.\ b_j X_{jit} + \ldots.\ b_{it} \tag{4}$$

in which the use level (Y_{it}) for area i in year t is described by several variables (X_{it}). It was found that for U.S. Forest Service areas such variables as percentage of area over 7000 feet in elevation, road construction in adjacent National Forests, travel time, precipitation, population within a certain distance, size of wilderness area, number of lakes and number of entry points are important.

Regarding gravity-type models, many attempts are made for improvements and implementation. Freund and Wilson (1974) give an example of an implementation by estimating a gravity-model to explain recreational travel and participation. In concentrating on the implementation method and the nature of results, they found that a major task was to make physically observed measurements serve as proxies for parameters specified by the gravity-model. In addition, they found it necessary to choose a reasonable set of meaningful predictor variables.

According to Wolfe (1972), a disadvantage of the gravity-model is the tendency to overestimate the number of short recreational trips and to underestimate the number of the long ones. He therefore constructed a so-called inertia-model:

$$V_{ij} = K \frac{P_i^p\ C_j^c}{D_{ij}^d} \cdot D_{ij}^{\left[\frac{\log D_{ij}/m}{n}\right]} \tag{5}$$

in which the same variables (population P, capacity C, and distance D) are used but the distance function itself (or the description of the reaction of recreationists on distance) is transformed. Whether this type is more adequate to simulate reality still is to be proved for different forms of outdoor recreation. It would be worthwhile to try it out for forest areas.

Taking all things together, it is clear that the modeling itself is something to be followed critically. Other simulation procedures for outdoor recreation demand may become operational in the near future.

Regarding the Origin Factor

An important aspect of demand-modeling for outdoor recreation is the achievement of obtaining knowledge on the reasons of people to seek recreation in the outdoors. Many ideas have been formulated, less research has been done, and almost no results have come up.

Up to now the research in this field has been restricted to analyses of the influence of socio-economic variables upon demand (measured mostly as number of trips), although other approaches also have been followed. La Page and Ragain (1974) found that a large change in camping (51 percent of former campers were either camping less or had dropped out of the camping market) was related to a change in the style of camping itself, and to changes in the family cycle, although the latter gave not in a consistent pattern. These findings point to the problem of the substitutability which has been defined by Hendee and Burge (1974) as "the interchangeability of recreation activities in satisfying participants' motives, needs, wishes and desires." It is quite obvious that research, especially dealing with this aspect of the demand, needed.

How various socio-economic factors have their influence upon outdoor recreation participation is shown by different researchers. Recently McEvoy (1974) experimentally investigated the influence of the distribution of the working time. From the research it appeared that "substantial increases in the consumption of outdoor recreation will result if the four-day workweek is adopted by a significant segment of the work force." For planning outdoor recreation the future distribution of leisure time will be very important. According to Bijkerk (1975) it is important to know whether

"we are moving towards less working hours per day, less working days per week, less working weeks per year or less working years in a life-time."

In the approach of Cesario (1975), the demand-part of the trip-distribution can be analyzed more thoroughly. In his research only population and income were accounted for, but it is necessary and it should be possible to enlarge the efforts in this direction. Lintsen (1975) constructed a special demand function, in which the distribution effect was not included, however:

$$\alpha_i = \beta_o + \sum_{n=1}^{12} \beta_n \cdot hhcat_m^{(n)} + \sum_{n=13}^{n=16} \beta_n \cdot won_m^{(n-12)} + \beta_{17} \cdot mob_m + \beta_{18} U_m \qquad (6)$$

This formulation shows that the demand (α_i) depends on household-categories (hhcat) which were based on income and family cycle as also on the type of house (won), the possession of a car (mob) and the level of urbanization (U) of the origin.

Regarding the Linkage Factor

The problem of the reaction of people to distance (or on factors derived from distance, such as travel-time or costs) has been tackled by many investigators. Wolfe (1972) initiated a new approach by using a different reaction-to-distance-function based on the so-called inertia of starting up and on the inertia of movement. The starting up inertia is caused by the fact that "a great many people may not wish to make a trip of any length, however short," while the inertia of movement is caused by the fact that "among the minority of people who indulge in lengthy trips, a still smaller minority finds travel itself so stimulating that the farther they go, the farther they want to go."

This has led Beaman (1974) to analyze the reaction to distance as a function of distance. On the basis of an analysis of five gravity-functions, he found that there are cased in which (a) each new mile to be traveled offers more resistance than the last; (b) each new mile to be traveled offers less resistance than the last; and (c) each new mile to be traveled has a constant resistence.

These results suggest that the reaction to distance is hard to understand, especially because it is also related to the distribution of outdoor recreation facilities itself. This last aspect has been stressed by O'Rourke (1974), who says it is "a function of the structure of opportunities available to the recreationists."

From the foregoing it can be concluded that this part of the demand has to be investigated thoroughly. One has, however, to keep in mind that it will be very complicated since the availability and distribution of opportunities plays an important role. Is the road a factor on its own or is it a part of the site? In addition, in many cases the travel itself can be enjoyable. This probably causes the inertia of movement (Wolfe 1972).

Regarding the Destination Factor

The leading problem in analyzing the destination is whether it can be analyzed objectively (i.e., based on hard facts such as acreage of parking areas, playing fields, etc.) or whether it has to be analyzed subjectively (i.e., using perception of the area by the recreationists) as well.

In the approach of Cesario (1975) only objective variables were used, such as number of acres, number of camping units, length of beach, etc.

An inventory of camping-sites in the Netherlands by IJkelenstam (1974) showed that the preferences of campers with regard to the location of the sites are closely related with forests and seacoast (fig. 1). The attractivity (or the attractiviness) in its essence is more subjective, however, in his "analysis of visits to outdoor recreation sites in the vicinity of a large town in the Netherlands (Eindoven)," Lintsen (1975) found that attractivity determined by calibration of gravity-models per socio-economic groups shows large differences (table 1). The findings show that (a) the ranking of the areas (first, second, etc.) differs from household category to household category; and (b) the variancy of the attractivity-indices per area among the household categories is large.

From this it can be concluded that the attractivity of sites depends not only on the site-properties but also on the differentiation in demand.

This shows that studies regarding the perception of especially wilderness and forestry areas should be encouraged in the near future. The first steps on this difficult path have been made, however.

Figure 1--Campers in the Netherlands preferred camping sites in forests or along the seacoast, according to an inventory made by Ijekenstam (1974).

Table 1— The attractivity-indices of 12 recreation areas for 12 household categories (hhcat) depending on income and family cycle.

area	hhcat											
	1	2	3	4	5	6	7	8	9	10	11	12
1	.070	.110	.053	.069	.074	.036	.049	.112	.067	.064	.098	.047
2	.026	.060	.028	.033	.042	.069	.049	.067	.041	.027	.049	.055
3	.005	.010	.010	.007	.003	.005	.005	.008	.006	.014	.009	.008
4	.043	.040	.048	.028	.034	.042	.060	.055	.047	.031	.052	.046
5	.092	.053	.117	.104	.152	.111	.083	.107	.160	.124	.195	.202
6	.038	.013	.028	.032	.026	.017	.040	.041	.019	.008	.038	.012
7	.253	.237	.115	.234	.172	.211	.251	.127	.181	.204	.181	.187
8	.192	.131	.184	.160	.188	.178	.179	.279	.213	.136	.262	.132
9	.090	.095	.152	.083	.130	.123	.070	.050	.096	.106	.036	.117
10	.138	.097	.097	.179	.073	.096	.092	.102	.057	.102	.017	.035
11	.045	.087	.082	.030	.085	.071	.067	.029	.062	.105	.034	.135
12	.008	.068	.087	.040	.021	.040	.057	.023	.051	.079	.029	.025

Source: Lintsen 1975

Tuan (1974) studied environmental perception, attitudes, and values, while Peterson (1974) studied the perception of wilderness among the different groups about some activities that were approved of (e.g., paddle canoeing and fishing) and others that were disapproved. Differences were found in the perception by recreationists and managers. Carls (1974) reported that the perception of certain landscapes is negatively correlated with the "area of people and the area of high development," positively correlated with "area of stream, of waterfall and of lake."

The research on the destination factor has been done in two ways: (a) studying the properties (hard facts) of the area and relating these to the attractiveness; and (b) studying the perception by recreationists of the area.

An approach including perception and hard facts is needed. The recently published report of the Committee on Assessment of Demand for Outdoor Recreation Resources (1975) should be mentioned. In this report attention is paid to the planning and social and economic policy of outdoor recreation and to methods of analyzing demand. Special topics are the demand for alternative types, the demand for site-specific outdoor recreation resources, a socio-psychological definition of recreation demand, and the estimation and use of models.

CONCLUSIONS

The following general conclusions regarding the demand for outdoor recreation in forests can be drawn:

1. Demand studies are a vital part of planning outdoor recreation facilities in general. This also accounts for the type of facilities and projects which are predominantly situated in forest areas or which are formed by the special layout of the forest itself.

2. Research regarding the substitutability of the demand should be encouraged. Insight in this matter opens the possibility for planners to adjust the plans in a better way to the natural sutability of forest areas for outdoor recreation.

3. Demand studies based on model-approaches have been performed in several ways. Improvements were made in recent years. Nevertheless the type of model to simulate trip distribution in particular to forest areas should be object of further studies.

4. A separation of origin-, linkage- and destination-factors in demand-models is very often used. Both the study of the way in which these factors should be distinguished and the analysis of these three basic factors only have been started, however. More research is needed, especially for forest areas, given the fact that up to now not enough is known about the factors (variables) determining their attractiveness. Perception research should be mentioned in this regard.

5. For the analysis of the origin-factor studies regarding background variables should be performed. The reaction of recreationists on distance to forest areas is a special problem since nothing is known about the perception of travel distance as related to the proposed visit to forest areas. More and detailed studies on this part of the demand-modeling are needed.

Finally, some remarks about planning in forestry and recreation by Bijkerk (1975) are appropriate:

1. A more systematic approach, according the sequence allocation-capacity-layout, to determine the requirements of new recreation facilities in forests, will improve the effectiveness of the plans, as well as lower the difficulties of acquiring funds for outdoor recreation.

2. A classification of forests according to recreational potential will prove to be of great benefit to planning an increased recreational use. Research on the possibilities of making such classifications should be encouraged.

3. Data on recreational activities should be included in the census, as such data are becoming indispensable for adequate planning of facilities for outdoor recreation.

VERBESSERUNG DER FRAGEUNTERSUCHUNGEN FUR DIE PLANUNG VON FREILUFTERHOLUNG

Zusammenfassung

Die Frage nach Freilufterholung, besonder in Waldgebiete, ist klar. Zukünftige Aenderungen dieser Fragen mit Bezug auf Zahl und Richtung, müssen untersucht werden wenn es sic um die Planung von Anlagen händelt. Die Lösur einer Reihe Probleme mit Bezug auf Feststellur von Art, Stelle, Kapazität und Einrichtung vor Freilufterholungsanlagen ist notwendig. Eine Beschreibung ist gegeben worden von 'Gebrauchs

modelle' die zuerst entwickelt worden sind um die Fragen für bestimmte Stellen zu beschreiben, gleich wie die Nachteile dieser Modelle. Besonders bezüglich die Unmöglichkeit diese für andere Gegenden zu benützen. Um diese Nachteile zu überwinden ist das nächste Modell, das 'Schwerpunktmodell' entwickelt worden. In diesem Modelle werden Alternatieven wie konkurrierende Stellen oder Gegenden planmässig eingebaut. Die Nachteile dieses Modelles sind zweifaltig:

-- die Unmöglichkeit drei Grundlagen dieses Modelles, nämlich Ursprung, Bestimmung und Verbindung, deutlich zu separieren und zu extrahieren. Die Separation der Einfluss dieser drei Grundlagen auf Fahrtverteilung ist statistisch sowohl wie konzeptisch schwer durchzuführen

-- die Bedeutung jener drei Grundlagen ist nicht eingehend geprüft worden. Einsicht in den Hintergrundvariabelen von 'Push (Ursprung) und 'Pull' (Bestimmung) sowohl wie in der Abstandperzeption (Verbindung) fehlen.

Im Rahmen neuere Entwicklungen sind Vorschläge gemacht worden und Untersuchungen durchgeführt worden um diese Nachteile zu überwinden. Neue Analysen mit Bezug auf Fahrtverteilungen ebenso wie auf Hintergründe der Ursprung und Bestimmung sind fertig oder werden gemacht. Einige Beispielen sind gegeben worden.

Hinzu sind einige Schlussbemerkungen gemacht worden. Frageuntersuchungen sollen in der Zukunft durchgeführt werden. Das Problem der Substitutionsfähigkeit der Frage müssten bei noch kommende Untersuchungen mehr benachdrückt werden. Dies gilt auch für die Analysen der Fahrtverteilungen, die Separation in Ursprung, Verbindung und Bestimmungsfaktoren und die mehr detaillierten Analysen dieser Faktoren.

L'AMELIORATION DES ÉTUDES DE LA DEMANDE COMME MOYEN DE PLANIFICATION DE LA RECREATION EN PLEIN AIR

Resumé

La récréation en plein air, plus particulièrement sous forêt, est très recherchée. Des modifications fûtures de la demande, quant à la quantité et l'orientation, devront être étudiées quand il s'agit du planning des facilités. La solution des problèmes relatifs à la détermination proprement dite à la location, à la capacité et à l'amenagement des projets en plein air est d'une importance majeure.

Une description des 'modèles d'utilisation' qui avaient été développés initialement aux fins de décrire la demande pour des sites precises, a été donnée aussi que des desavantages de ces modèles en ce qui concerne l'impossibilité de les utiliser pour d'autres regions.

Un deuxième modèle, 'du type gravité', était construit pour surmonter ces desavantages par l'inclusion explicite d'alternatives (d'autres sites ou regions) dans le modèle. Les limites de ce deuxième type sont:

-- L'impossibilité de séparer clairement les trois facteurs de base: origine et destination du voyageur et accessibilité du site. A là fois sur le plan de conception et de statistique la destillation de l'influence de chacun de ces trois facteurs sur l'utilisation des facilités est difficile.

-- La signification de chacun des facteurs n'a pas été recherchée profondément et notre comprehension reste insuffisante.

Lors des développements plus recents des propositions ont été formulées et des études ont été entamés pour faire face ces deux limites. Des analyses nouveaux relatifs à la distribution des voyages ainsi qu'à la destination et à l'origine des voyageurs ont été faits ou sont en voie de realisation. Quelques examples ont été donnés.

A la fin il a été remarqué que des études de la demande seront necessaire dans l'avenir et que le problème d'une substitution possible de cette demande devra recevoir plus d'attention. Ceci est valable aussi bien pour les analyses de distribution de voyages, pour la separation des trois facteurs origine, accessibilité et destination que pour l'analyse de ces groupes de facteurs de façon plus détaillée.

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Forecasting the Demand-Response to Changes in Recreational Site Characteristics

Peter Greig[1]

Abstract--A new method is presented for forecasting the short-term change in numbers of visitors at an area, after some change in the recreational quality there. A group of recreation areas may be substitutes for the area of concern. Recreationists decide on trips to particular areas, depending on the relative costs and quality characteristics of an area, and on their particular preferences for those characteristics. Both the characteristics as well as the distribution of preferences in the community, can be described mathematically and a model of recreationists' choices developed. Using observed data on costs, characteristics, and numbers of visits at the areas in the group, the model can be used to forecast new choices after some change in the characteristics of an area. Simple numerical examples illustrate application of the model.

In forestry practice, many operations involve alterations to the forest landscape. These alterations often affect the recreational quality of the area concerned--even if recreation is only one of the multiple uses involved. In evaluating whether or not to make the alteration, an essential piece of information will be an estimate of the change, if any, in the number of visitors to the area.

This paper describes a new method of forecasting the change in numbers of visitors (and their origins) after a specific change in the recreational quality of a forest or any other rural area.

Recreational quality is defined here as comprising the physical characteristics of recreational areas that may influence households in their choices between such areas. Recreational characteristics have been the subject of much research, which can be divided into two classes.

The first class is concerned with estimating, by direct responses from recreationists, the relative importances of various characteristics, the overall "attractiveness" of an area, or both. This class is characterized by its dependence on stated preferences (Sinden 1973, Cordell and James 1972, Shafer and others 1969, Hoinville 1971, Juurand and others 1974).

The other class is concerned with estimating, by statistical methods, the relationship between visitor numbers at recreation areas, and the various characteristics of those areas. Usually, a causal relationship is implied, on the supposition that visitors choose according to their preferences for characteristics. Thus, the second class of methods may be said to depend on revealed preferences. Mostly, the methods have involved the use of multiple regression analysis (Johnston and Elsner 1972, Lime 1971, Seneca and Cicchetti 1969, Shafer and Thompson 1968, Holman and Bennett 1973, Cheung 1972). More recently, a method has been developed to take into account the suspicion that characteristics may not be entirely independent in their separate contributions to a recreationist's preferences for an area. Thus Cesario (1973) used the Automatic Interaction Detector (A.I.D.) Analysis which allows for possible interaction between variables.

The "stated preference" methods all place the respondent in a hypothetical choice situation, so there are serious doubts about whether the results will predict actual choices. The "revealed preference" methods developed so far have modeled the relationships between characteristics and observed choices without specifying the underlying causal phenomena. In that sense, these models are incompletely specified, so that predictions from them may be inaccurate.

The new method described in this paper, while belonging to the "revealed preference" class, differs from its predecessors by incorporating explicitly the underlying causes of observed choices. Specifically, households

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are considered to make choices that maximize expected satisfaction, subject to budget constraints. Thus, the method accords with accepted utility theory, as expounded, for example, in Green (1972), with one important difference. Satisfaction is taken to be a function of recreation area characteristics, rather than simply of the areas themselves. The method, therefore, follows a development of accepted utility theory attributed most frequently to Lancaster (1966).

The basic elements of the new method will be presented and illustrated with simple numerical examples, with some suggestions for empirical estimation.[2] The method has three basic elements:

(i) Define the group of recreation areas from which the household may choose, once it has decided to make a recreation trip. The group must include all areas that are potential substitutes for the area chosen.

(ii) Isolate and measure the characteristics likely to influence the household's choices between members of the group.

(iii) Estimate the expenditure of households on recreation trips, and relate this to the relative preferences for the characteristics.

The definition of the group of recreation areas is a well-known problem in recreation and econometric studies. Hence, it is left until last in the ensuing description, so that attention can be focused on the more innovative aspects of the present method. Therefore, the description begins on the understanding that, for a recreation area of particular concern to decisionmakers, the group of substitute areas has already been defined.

THE "BEST" AREAS AT A GIVEN COST

To illustrate the method, consider a hypothetical problem and setting. Suppose the problem involves alterations to a particular ski area. For simplicity, assume only one center of population is involved. The group of recreation areas to be considered, therefore, includes all ski areas accessible to that population center, assuming for simplicity that these are the best substitutes for the area concerned.

[2] Empirical work on the model is under way at the Department of Forestry, Oxford University. The financial support of the Forests Commission, Victoria, Australia, is gratefully acknowledged.

Consider a "representative" household from this population center. A "household" may, of course, comprise an individual, or a family--the term is used to denote the unit that makes the choices.

The method makes three basic assumptions about the behavior of a household:

1. A household is well-informed about the characteristics of all the accessible areas,

2. A household allocates a part of its annual income to skiing trips during the year, and

3. A household chooses the area (or areas) that provides the best skiing quality for the given budget--skiing quality being some function of area characteristics.

To illustrate the analytical procedure, consider just one of the household's objectives in going to a ski area for a weekend. Say this objective was to maximize the distance covered on the snow, travelling downhill at some given rate of descent. For this objective, several area characteristics would be important, including snow quality, slope quality, lift quality, and others. Taking just the first two to simplify the illustration, it would be necessary to define the characteristics in terms of some measurable, physical attributes that governed the distance covered by a skier travelling downhill at a given rate. For example, the steeper the slope, the shallower the traverses needed for a given rate of descent; so the greater the distance covered in one weekend, <u>ceteris paribus</u>. A similar situation exists for "crisper" snow surface conditions. Of course, allowances would have to be made for other factors, such as icy conditions, or dangerously steep slopes, affecting safety, but these need not affect the present illustration.

The two characteristics might be measured for each ski area on weekends during a given snow season. The results for each area would be averaged to yield quantities for an average weekend. If, for example, there were just four ski areas within a weekend's travelling time, then the average quantities might be:

Area number:	Snow quality (B_1)	Slope quality (B_2)
1	25	50
2	85	25
3	25	50
4	75	75

If two weekends were spent at a given area, then the quantity of each characteristic would be twice that shown in the tabulation because the distance covered on the snow would be doubled. Thus, considering snow quality on its own, the household would have to make three trips to area 1 in order to obtain the same quantity as could be obtained on just one trip to area 4. But the household must consider the relative quantities of both characteristics on all the areas.

In addition, the household has to consider the relative costs of the four alternatives. Let these costs, including travelling, accommodation and skiing, be, on average:

Area number:	Average costs
	\$ (p)
1	25
2	50
3	100
4	50

If the household allocated, say \$100 for the year's skiing weekends, then the maximum number of trips to each area would be:

Area number:	Maximum weekends
	(x)
1	4
2	2
3	1
4	2

It follows that the maximum quantities of each characteristic that could be obtained at each area would be:

Area number:	Maximum quantities of snow quality	Maximum quantities of slope quality
	$Z_1 = (B_1).(x)$	$Z_2 = (B_2).(x)$
1	100	200
2	170	50
3	25	50
4	150	150

These results can be illustrated geometrically (fig. 1). The initial choices that face the household can be reduced from four to three. Area 3 would be an inefficient choice because more of both characteristics could be obtained, for the same budget, at any of the other three areas, or some combination of them. The household was not obliged to choose just one of the available areas--it could make a number of trips to more than one area, so long as the budget was not exceeded. In this case, the maximum quantities of characteristics obtained would fall somewhere along the straight lines 1-4, or 4-2, or both. Obviously, not all points on these lines are obtainable, because for a single household, fractions of trips cannot be made. But this is not a constraint when large numbers of households are considered. The lines 1-4 and 4-2 represent all efficient combinations of trips to the ski areas; therefore, they constitute what has been called the "efficiency frontier" (Lancaster 1966). They represent all the "best" trips for the given budget.

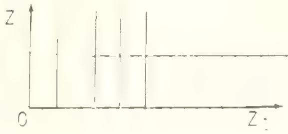
The relevant characteristics for the group of areas can thus be identified empirically. If, on adopting some set of characteristics, an area appears to be inefficient (i.e., falls beneath the efficiency frontier), yet receives significant numbers of visitors from the given population center, then the characteristics must have been wrongly chosen, or wrongly measured. Similarly, if an area appears efficient yet receives no visitors, then the same conclusion would be drawn.

Once the efficiency frontier has been defined, the actual point on it the household would choose depends on the relative importance the household attaches to the two characteristics. Thus it is necessary to consider the household preferences.

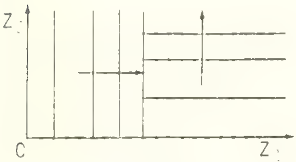
HOUSEHOLD PREFERENCES

Household preferences can be represented by indifference curves which trace out the trade-off the household is prepared to make between the characteristics. If, for example, snow quality is poor at a given area, the household might be prepared to select another area with better snow, even if the slope quality is a bit worse. This selection can be illustrated by curves (fig. 2). Each curve traces out the combination of quantities of Z_1 and Z_2 between which the household is indifferent. The curves further from the origin represent higher levels of utility (i.e. "satisfaction" or "preference"); in fact they may be best thought of as contours of a continuous surface. From here on, the term "utility function" will be used to describe this surface. The curves will be inclined more steeply toward one of the axes if the household has a stronger relative preference for the characteristic identified with that axis than for the other characteristic.

In the extreme, if the household was interested in just one of the characteristics, say Z_1, then the utility functions contours would consist of straight lines, thus:



If the characteristics come into play sequentially as suggested by Juurand and others (1974), the contours might appear as:



It is possible to superimpose figure 2 on figure 1, as shown in figure 3.

The household may seek to maximize the quantity of site characteristics for a given cost, irrespective of the number of trips. In respect to the snow quality characteristic, for example, the household could obtain the same quantity by taking either one weekend at area 4, or three weekends at area 1. The household might be indifferent between these two alternatives, ceteris paribus, if the overall costs of each were equal. The costs, of course, would have to include, in addition to travel costs, the opportunity costs of time, since one alternative takes up three times as many weekends as the other. It is possible to allow for this in empirical work (see, for example, Keith and Workman 1975, Beesley 1965). Under these conditions, the household's choice situation is illustrated in figure 3.

Under these circumstances, the household would reach its highest level of utility at just one point on the efficiency frontier. This point, T, is where the utility function is just tangent on the efficiency frontier. T falls exactly midway between points 1 and 4, which means that the household's budget is divided equally between areas 1 and 4. Thus, letting the household's budget be \$100, the optimum combination of trips is:

Area number:	Optimum trips: household H_1
1	2
2	0
3	0
4	1

An individual household would, therefore, never need to visit more than k areas, where k is the relevant number of characteristics.

But there were other households in the population center, and since they may have had different preferences, they must be considered.

COMMUNITY PREFERENCES

Let the household just discussed by denoted by H_1, and let there be just three other households H_2, H_3, H_4. Consider each in turn. Firstly, imagine H_2 has the same annual budget for skiing weekends as H_1 \$100, but it has a stronger preference than H_1 for Z_1 relative to Z_2. This means that H_2's utility function would be inclined more than H_1's towards the Z_1 axis (fig. 4). As a result of this inclination, the point of tangency on the efficiency frontier is further towards the Z_1 axis. In fact, it is "tangent" directly upon point 4, implying that H_2 devotes its whole budget to area 4 exclusively. Thus the optimum combination of trips for H_2 is:

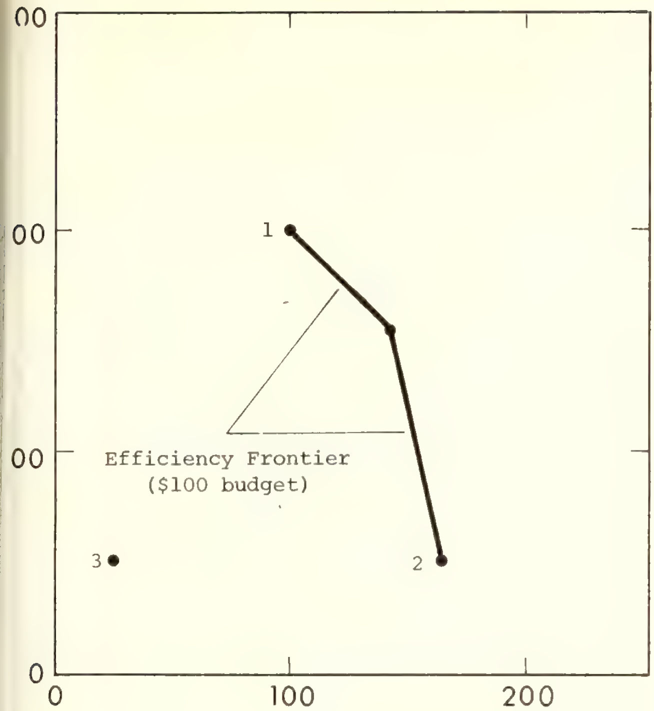
Area number:	Optimum trips: H_2
1	0
2	0
3	0
4	2

H_3 has exactly the same preferences and budget as H_2, so that its optimum combination of trips is the same. These can be added to yield:

Area number:	Optimum trips: H_2 + H_3
1	0
2	0
3	0
4	4

H_4 has an even stronger preference for Z_1 than for Z_2, so that its utility function is tangent even further towards the points 4 and 2. Hence its budget is divided equally between Z_1 axis: midway between areas 2 and 4. But H_4's budget is \$300, so that the original efficiency frontier (drawn for a budget of \$100) is expanded by a scalar factor of 3 (fig. 4). Thus H_4's optimum combination of visits is:

Area number:	Optimum visits: H_4
1	0
2	3
3	0
4	3



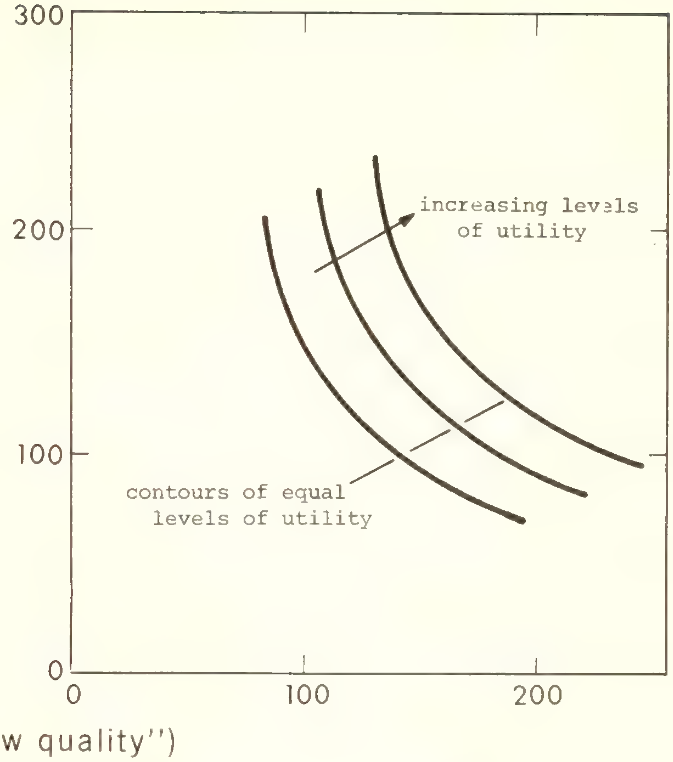


Figure 1--Maximum quantities of two characteristics obtainable at four ski areas with an annual budget of $100.

Figure 2--Family of indifference curves (the "utility function") of a household.

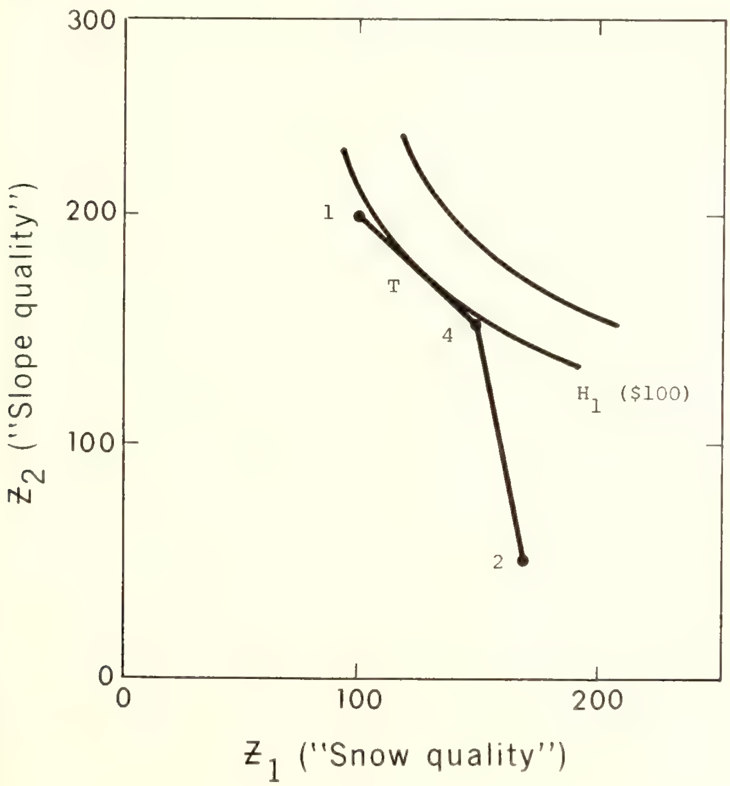


Figure 3--Optimum choice for household H_1 occurs at T, the point of tangency of its utility function on the Efficiency Frontier.

The total number of visits for the whole community is:

H_1		$H_2 + H_3$		H_4		Community
2		0		0		2
0	+	0	+	3	=	3
0		0		0		0
1		4		3		8

Thus, for a given efficiency frontier, a certain distribution of preferences coupled with a certain distribution of expenditures result in a certain number of visits to the areas concerned. The same number of visits would have resulted if, instead of H_4, there had been two households with H_4's preferences, each with a budget of \$150. Similarly, if H_3 had not existed, but H_2 had allocated a budget of \$200, the same results would have been obtained.

This example has illustrated the essential components of the model of recreationists' choices. In a model of a real situation, there are many characteristics, many areas, and many population centers to be considered, and the mathematics required uses the techniques of non-linear programing.[3] But before the model can become useful to the aims set out in this study, it needs to be calibrated with data from actual recreation areas.

CALIBRATING THE MODEL

Of the model components described, all can be measured directly except the distributions of preference and expenditure. Yet these distributions--or a combination of them --are critical to the applications of the model. Therefore, they must be estimated, and the most straightforward approach is to estimate a function, F, that relates total expenditure (= number of households by average expenditure) to preferences, both with respect to the community concerned. To do this, some numerical index of preferences must be specified. This can be done by specifying the utility functions of figure 2 mathematically. One simple, convenient form would be:

Similar calculations for the other utility functions yield the results:
where u denotes utility level, Z_i denotes quantity of characteristic i, and α_i are parameters such that

$$\alpha_1 + \alpha_2 = 1, \quad 0 \leq \alpha_i \leq 1.$$

The relative strength of preference for Z_i is indicated by the relative size of α_i. Thus in the example discussed previously (fig. 4), H_1's utility function might have been:

$$u = Z_1^{\frac{1}{4}} \cdot Z_2^{\frac{3}{4}}$$

indicating that H_1 preferred Z_2 more strongly than Z_1, in the sense that a 10 percent increase in Z_1 would produce a 2.5 percent increase in the utility level, whereas a 10 percent increase in Z_2 would produce a 7.5 percent increase in the utility level. This form for the utility function is chosen for mathematical convenience. It seems to imply cardinal utility, though several transformations (e.g., a logarithmic transformation) would maintain the same preference ordering, and do equally well in the model, yet allow the utility levels to vary monotonically.

It can be seen, therefore, that the utility parameters provide a convenient numerical index of preferences. In the example with two characteristics, it is necessary to specify only one of the parameters, say α_1, because the other is immediately defined by $\alpha_2 = 1 - \alpha_1$. Thus the preferences of the households (H) discussed previously may be put down as:

Item:	H_1	H_2, H_3	H_4
Total expenditure (F)	(100	200	300)
Preferences (α_1)	(1/4	1/2	3/4)

The values of these parameters for the various households are not known, however, and cannot be ascertained directly, except by using "stated preference" methods (e.g., Sinden 1973), which have a major weakness already discussed. The alternative approach is to estimate the parameters indirectly, using observed data on actual choices, by adopting the following steps:

1. Postulate values of the parameter α_1^k for k discrete utility functions that are though likely to exist in the community. For example, postulate three utility functions, as follows:

	Utility function number k		
	1	2	3
Parameter (α_1^k)	(1/4	1/2	3/4)

[3] Such a model has been developed by the author for use on an ICL 1900 Computer.

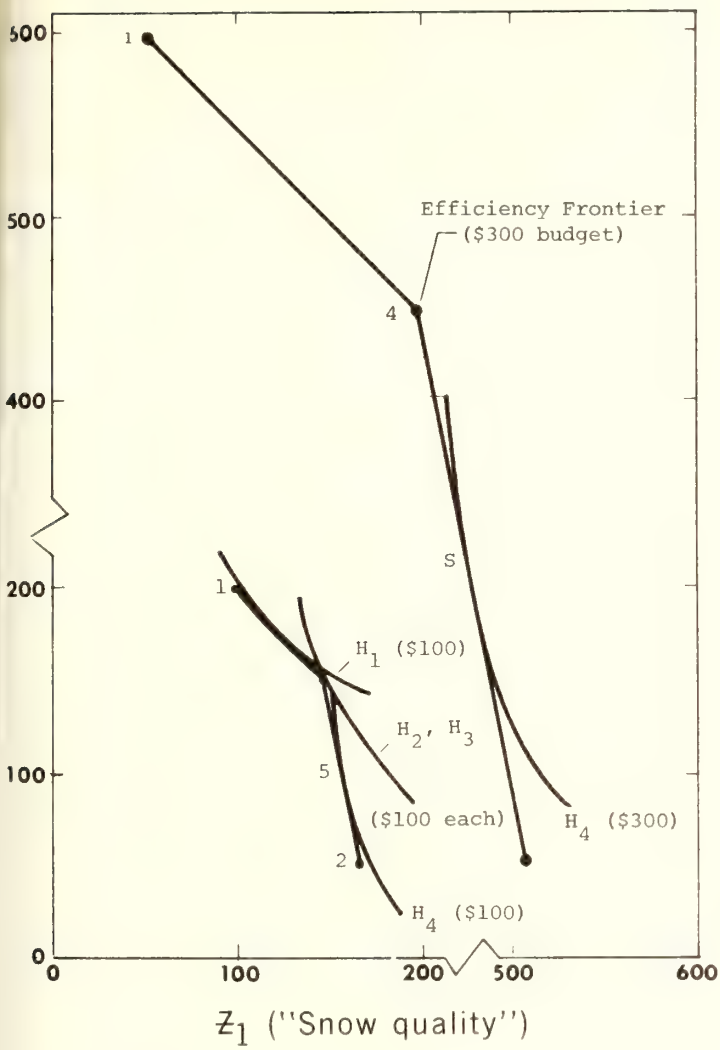


Figure 4--Utility functions for four households, H_1, H_2, H_3, H_4, and their respective optimum choices.

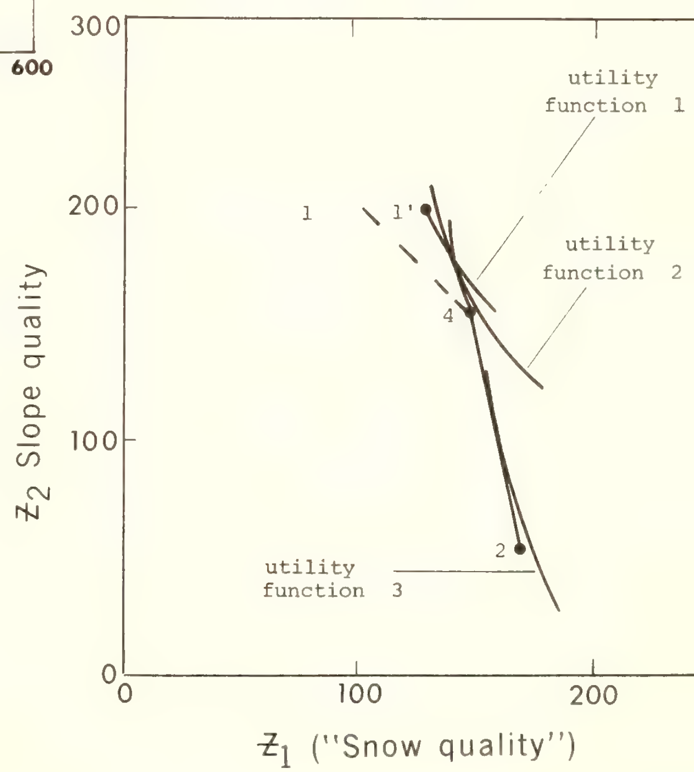


Figure 5--After characteristic Z_1 is altered at Area 1, the Efficiency Frontier near Point 1 swings outwards to Point 1'. The points of tangency of two of the three utility functions shift towards Point 1'.

(The same utility functions as used previously have been adopted for convenience.)

2. Determine the proportions of expenditure, λ_k^j, allocated to the j^{th} area by the households having the k^{th} utility function. This information is derived from the points of tangency of the efficiency frontier of the respective utility functions. Conveniently, having postulated utility functions that have already been used in examples, these proportions of expenditure (λ) have already been calculated previously:

Area number:	Utility function number 1	2	3
1	1/2	0	0
2	0	0	1/2
3	0	0	0
4	1/2	1	1/2

3. Postulate some likely form for the function F. For the simple example in hand, the obvious choice is a linear function:

$$F = b_0 + b_1 \alpha_1^k + \epsilon \qquad (1)$$

where b_i are coefficients and ϵ is the random error term.

The linear form of F would imply that there is greater expenditure (either more households, or more average spending, or both) by people with stronger preferences for characteristic Z_1 than for characteristic Z_2. (There is no a priori reason why the form would be linear; it is used here purely for convenience of exposition.)

4. Define the expressions giving the expected number of visits to each area:

$$x^j = \sum_{k=1}^{3} \lambda_k^j \cdot F \cdot \frac{1}{P^j} \qquad (2)$$

where x^j denotes the number of visits to the j^{th} area, P^j denotes the cost of one weekend in the j^{th} area, and the other terms are as defined above.

This is simply a formal expression of the statement made earlier that a certain distribution of preferences and expenditures implies a certain number of visits to the respective areas. Thus, by corollary, a certain observed number of visits implies a certain distribution of preferences and expenditures. Thus, inserting (1) into (2), derive:

$$x^j = \sum_{k=1}^{3} \lambda_k^j \cdot (b_0 + b_1 \alpha_1^k) \cdot \frac{1}{P^j} \qquad (3)$$

in which all variables are known except the coefficients, b_i, which can be estimated.

To illustrate this estimation procedure, let the observed aggregate number of visits to the respective areas from the given population center be (as before):

Area number:	Observed visits: community (x)
1	2
2	3
3	0
4	8

Thus there will be three equations of type (3). Inserting values for P^j, and λ, these equations can be solved:

$$b_0 = 0$$

$$b_1 = 400$$

Thus $\hat{F} = 400\alpha_1^k$

where $\hat{F}$ indicates the estimated value of F. (In this example the estimate fits the data perfectly, so $\hat{F}$ = F precisely, with no random error.)

$\hat{F}$ thus estimates the distribution of expenditure as a function of preferences, as it exists at the time of estimation. It is, therefore, a general statement about the community preferences in the population center; no attempt is made here to associate $\hat{F}$ with particular households in terms of socio-economic characteristics (though these developments might be undertaken in future work on the model).

Once $\hat{F}$ has been estimated, the model is fully calibrated and ready to be used for short-term forecasting.

SHORT-TERM FORECASTING

When the characteristics of an area are changed, the efficiency frontier will be altered in shape. If the community preferences, represented by $\hat{F}$, remain unchanged (and in the short-term, unless there are marked changes elsewhere in the economy, there is no reason to think otherwise), then the community's

utility functions will be tangent upon a new set of points in the efficiency frontier. As before, this implies a new set of numbers of visits to the areas in the group. The model, once calibrated can be used directly to forecast this new set of visits.

To illustrate this process, imagine that at area 1, investments are made in slope-grooming and snow-making equipment, so that the average snow-quality rating, B_1, becomes 30, compared with 25 previously. Thus the maximum amount of this characteristic that can be had at area 1 for a budget of \$100 becomes 120, as against 100 before. The new efficiency frontier becomes as illustrated in figure 5, where the point 1' represents the altered site 1. The new points of tangency of the three discrete utility functions are also shown. The first two have points of tangency closer to 1' and further from 4 than they did originally. The contours of each utility function are taken to have constant slopes along all rays from the origin (i.e., they are homothetic). Hence, the new points of tangency are readily found, even though higher contours are reached in the process. The face 4-2 is unchanged, so that the point of tangency of the third utility function is not changed either. The new points of tangency imply a new set of proportions of expenditure, λ', going to the several areas. Let this new set (using the same ordering as before) be:

$$\lambda' : \begin{bmatrix} 3/4 & 1/4 & 0 \\ 0 & 0 & 1/2 \\ 0 & 0 & 0 \\ 1/4 & 3/4 & 1/2 \end{bmatrix}$$

(The new matrix, λ', has been simplified for illustrative purposes. The actual changes, for the data given, would be much smaller than shown.) Then, inserting the new values from λ' into equation 3, the new set of visits for each postulated utility function can be calculated directly. For example, taking the second postulated utility function:

$$\alpha_1^2 = 1/2$$

$$\hat{F} = 400 \cdot (1/2) = 200$$

(Note again that $\hat{F}$ is predicting perfectly, in a way that could not be expected in a real study.)

From equation 3;

$$x^1 = \lambda'^1_2 \cdot \hat{F} \cdot \frac{1}{P^1}$$

$$= (1/4) \cdot 200 \cdot (1/25)$$

$$= 2$$

$$x^2, x^3 = 0$$

$$x^4 = \lambda'^4_2 \cdot \hat{F} \cdot \frac{1}{P^4}$$

$$= (3/4) \cdot 200 \cdot (1/50)$$

$$= 3$$

Thus the forecasted set of visits is:

Area number:	Predicted visits: utility function 2
1	2
2	0
3	0
4	3

Similar calculations for the other utility functions yields the results:

$$\begin{array}{ccccccc} & & \text{Utility function} & & & & \text{Predicted visits:} \\ 1 & & 2 & & 3 & & \text{community} \\ \begin{bmatrix} 3 \\ 0 \\ 0 \\ 1/2 \end{bmatrix} & + & \begin{bmatrix} 2 \\ 0 \\ 0 \\ 3 \end{bmatrix} & + & \begin{bmatrix} 0 \\ 3 \\ 0 \\ 3 \end{bmatrix} & = & \begin{bmatrix} 5 \\ 3 \\ 0 \\ 6\ 1/2 \end{bmatrix} \end{array}$$

This result, compared with the originally observed set of visits, shows that, as expected, area 1 is attracting customers away from area 4, while there is no change to the visits in area 2. It will be apparent that, if the change in area 1 had been large enough, area 2's customers would have been effected as well.

To test the usefulness of the model as a predictor, it will be necessary to obtain data on variations in area characteristics and visitor numbers and origins, by time series. These data are not now available in Australia, but in the meantime, it would be helpful to obtain short-term data (say, one season) and to use the model to identify the relevant characteristics. Once identified, these data could then be collected over longer periods for more complete assessment of the model.

Finally, there is the problem of defining a separable group of areas, without which the model cannot operate.

DEFINING THE GROUP OF RECREATION AREAS

A fundamental requirement for the construction and application of the model is that the expenditure by the community on the various areas in the group remains (effectively) constant throughout the (small) changes that might be made in the characteristics of the area concerned. Essentially, this requirement entails that when conditions in the group are altered, substitution occurs only within the group. Also, it entails that changes outside the group have only the effect of possibly changing the budget allocated to the group. Hence, the definition of the group is a critical element in the modeling process; one that in practice must precede the other work described so far. Two possible approaches are now given for defining a group of recreation sites.

Grouping On Nature Of Characteristics

Lancaster (1971) has shown that if the characteristics of the area of particular concern are very special and not easily obtainable except in areas of similar nature, then such areas together are likely to form a group susceptible to analysis. This condition need not apply to all characteristics, as long as the "non-special" ones are much more readily available outside the group, than in it. On the basis of these criteria, ski areas clearly form a likely group, for one of the likely characteristics (namely, snow-quality--a surface suitable for skiing) can be obtained only in ski areas. Of the other likely characteristics (say, slope quality, access, services, accommodation) most, probably, would be more readily obtained in non-ski areas.

Such *a priori* reasoning would need to be supported by evidence, for example, from time series records of expenditure made on the group by households facing the same set of costs (e.g., in one population center). If this expenditure remains fairly constant, after allowing for demand shifting factors (such as changes in population size, per capita real income) despite the normal yearly fluctuations in snow quality at the various areas, then there is some ground for believing that the group exists as defined. The evidence would imply that households allocate a similar amount each year to skiing, deploying this budget to their best advantage, depending on the relative conditions at the various areas at the time of their trips.

Usually, though, these time series data are not available for the recreation sector, so that an alternative means of identifying the group would be required.

Grouping On Basis Of Demand Functions

An alternative method is to use data from a sample of households within the visitor catchment of an area. As before, it will be necessary, for purely practical reasons, to specify a likely group of n areas, preferably on the basis of their characteristics. The essential data to be gathered will include the number of trips x_i, made to the i^{th} area in the group, over a given period. In addition, the costs per trip, P_i would be estimated. Household socio-economic characteristics, that might effect demand, may be collected also.

The relationship between x_i and the costs of all n areas can then be examined by multiple regression analysis. Thus:

$$x_i = f\ (P_1, P_2, \ldots, P_i, \ldots, P_n)$$

where f ( ) means "some function of." This function, having been estimated from household data, is called a representative household demand function (Burt and Brewer 1971). Recreation areas with statistically significant coefficients in this function can be regarded as substitutes (if the coefficients are positive) or complements (if negative) for x_i. On this basis, the group can be defined.

These grouping methods are, at best, only approximate, since households in the community are free to substitute whatever they like next best, when the conditions in a recreation area change. Further, the focus above has been on the recreation areas, rather than on the individual households in the community. In other recreation research into substitution, the focus has been more on identifying the clusters of household types that have similar substitution patterns (see, for example, Romsa 1973 and Beaman 1975).

CONCLUSION

The model can be compared with its related predecessors in terms of three criteria: (a) data requirements, (b) predictive power, and (c) usefulness of output. The model requires much the same kind of data used in other "revealed preference" models, but in smaller amounts--especially area characteristics. Unnecessary data can be identified before collection by having an explicit understanding of the way in which characteristics influence choices. This is not so true of the regression models (e.g., Lime 1971 measured on each campsite more than 70 variables, of which only 3 were found significant), nor of the A.I.D. model, for which at least 2,000 observations are required (Cesario 1973). The "stated preference" models require in addition

to uncontrolled data on characteristics, a great deal of difficult interviewing.

As to predictive power, the present model is untried, as yet. But the other "revealed preference" models, especially the regression models, usually are shown to predict only within the data set used for their construction. Whether they will predict as well in new situations, when some of the unspecified variables (such as those to do with preferences) are changed, is another matter. The "stated preference" models, when tested as predictors against the regression models, have shown little consistency (e.g., Lime 1971).

Finally, the output of predictive models is most useful if there are policy implications, which demand that changes and potential changes in community welfare be estimated. However, often the output is simply given to a decisionmaker in the hope that it will assist him in some way. The present model, however, is superior in this respect to other models, as it can be used to forecast in quantifiable terms the social benefits that follow from potential changes in recreation-area characteristics.

ZUSAMMENFASSUNG

Eine neue Methode wird vorgestellt zur Voraussage von kurzfristigem Wechsel in der Anzahl der Besucher eines Gebietes auf Grund einiger Veränderungen, die Qualität der Freizeitbeschäftigungen dort betreffend. Die Methode schlägt verschiedene Möglichkeiten vor, eine Gruppe von Freizeitgebieten zu definieren, die als Ersatz für das in Frage gestellte Gebiet dienen könnten. Es wird behauptet, dass Erholungssuchende wählen, zu bestimmten Gebieten innerhalb dieser Gruppe zu fahren, mit Rücksicht auf die relativen Kosten und die Qualitätseigenschaften dieser Gebiete, sowie mit Rücksicht auf ihre eigenen speziellen Wünsche diese Eigenschaften betreffend. Beides, die Eigenschaften sowie die Verteilung der Eigenschaften innerhalb der Gemeinde werden mathematisch beschrieben, so dass es möglich ist, ein Modell der Wünsche der Erholungssuchenden aufzustellen. Sobald ein Modell mit Hilfe der Kostenanschläge, Qualitätseigenschaften und Anzahl von Besuchern in den Gebieten innerhalb einer Gruppe kalibriert worden ist, kann es dazu verwendet werden, neue Wünsche vorauszubestimmen, die auf Grund einer Veränderung der Eigenschaften eines beliebigen Gebietes innerhalb der Gruppe eintreten können. Die Methode wird an Hand einfacher numerischer Beispiele erläutert.

RESUMÉ

On présente là-dessus une nouvelle méthode pour prédire les changements à court terme dans le nombre de visiteurs sur un certain terrain après l'introduction sur ce terrain d'un changement dans la qualité de la récréation. La méthode propose des moyens pour déterminer un groupe de terrains de récréation qui peut remplacer le terrain duquel il s'agit. On prétend que "les récréationistes" choisissent leurs trajets en des terrains particuliers à cause des frais relatifs, des particuliarités des terrains et de leurs propres préférences pour ces particuliarités. Les caractéristiques et la distribution des préférences sont expliquées mathématiquement, pour laisser construire sur modèle les choix des "récréationistes." Après avoir calibré le modèle par l'emploi des données observées dans le domaine des finances, de la caractéristique, et du nombre des visiteurs aux terrains particuliés du groupe, on peut l'utiliser pour prevoir des choix nouveaux après des changements de caractéristique d'un terrain particulier du groupe. La description est augmentée d'exemples numériques simplifiés.

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On the Use of Home and Site Surveys in Recreation Research

Mordechai Shechter

Abstract--The pros and cons of home interviews versus on-site user surveys are briefly reviewed. The complementary relationship between them is illustrated by the findings of an extensive study on the demand for outdoor recreation at Mt. Carmel National Park, the largest national park in Israel. The need for expensive home interviews can be greatly reduced when the less-expensive, site surveys are properly constructed and implemented.

Outdoor recreation services are resource-based and as such can be used only at the point where the service is "produced" and provided. Market research designed to gage consumer preferences, consumption patterns, and other demand characteristics should recognize the difference between these services and other consumption goods and services for which that constraint is less restrictive, or nonexistent. Furthermore, unlike many other services, including other recreation services, the consumption unit is usually a group--family, friends, peers. The type, duration and intensity of outdoor recreation activities are therefore based on the interplay of desires and preferences of the individuals making up the group, their intra-group roles, and their physical inclinations or limitations.

Because of these characteristics, several approaches have been developed to measure the demand for these services, either for the purpose of estimating the number of users--present and future--or in terms of the range of recreational activities engaged in at recreation sites. Using these approaches, one can distinguish between behavior-oriented methods which focus on observing recreationists' activities at the site, and the more customary market research methods of interviewing people at home.

This paper seeks to show that out of the more commonly used market survey approach, the less expensive, on-site interview, might be just as efficient in gathering pertinent data as the more comprehensive home interview, and in many cases the latter can be satisfactorily replaced by the former. A brief description of various data-gathering techniques is included. Two surveys conducted in conjunction with a demand study of a large Israeli recreation park and a comparison of the two on the basis of a statistical analysis are described.

SURVEY AND NON-SURVEY TECHNIQUES

Of the non-survey group of techniques we could briefly mention the method of physical evidence in which for example, a vinyl thread is used as an indicator of use intensity. If placed near an area which draws relatively large crowds, it of course wears faster than if placed somewhere else. Mechanical and electronic devices also serve as use intensity indicators. Here we may list car detectors which record the number of vehicles entering and leaving an area, and counts based on aerial photographs. Finally, we should mention the method of direct observation in which an observer records the behavior of recreationists.

The other methods for obtaining information on consumption patterns and overall demand for outdoor recreation are all based on various forms of market surveys. There are several means for obtaining the information through such a survey: self-administered questionnaires, telephone interviews, and personal interviews. The latter is the most widely used; it assures the highest rate of response, and allows a more in-depth analysis. I shall restrict my discussion to this type of survey and concentrate on the two possible tactical approaches to the conduct of the interview--home versus in-site interview. The former is conducted at the interviewee's abode, while the latter is conducted at the recreation site.

The Home Interview

The interview at home allows for a thorough interview. Since it is usually based on a representative sample drawn from the entire population of a given geographical area (city, region or country), it naturally covers visitors as well as individuals who do not participate in any recreational activity, or seldom do. It therefore enables the investigator to analyse factors which affect the level of participation in any population group. Its main disadvantage is the need to base responses on recall rather than immediate experience. Home interviews are much more expensive than site interviews for two reasons: (a) since the population on which the home interview is based is

the origin population for an entire system of recreation sites, it is generally larger than the population of park visitors from which the on-site sample is drawn. Hence, home survey samples should usually be larger for the purpose of obtaining estimates with a given confidence interval (assuming the degree of variation in both populations is more-or-less equal); (b) the amount of interviewer's time per interviewee, including the time required to reach the latter's residence, is larger. In the site interview, visitors are concentrated at the site and can be more easily reached.

The Site Interview

The main advantage of the site interview is the immediacy of recall. It usually enables a more comprehensive coverage of the various activities in which recreationists engage. Its principal disadvantages are the relatively short time available for conducting the interview, and the often encountered difficulty in eliciting the cooperation of the recreationist. Obviously, such a survey relates only to that group in the total population which actually visits the site. Hence, the two surveys complement one another to a great extent--if one has the means to conduct both. This is rarely the case, nor is it really necessary as I now wish to demonstrate. Although the aim of the study described below was not to compare the two methods, I wish to draw on our experience in this regard, and arrive at certain conclusions which might be of some help in future investigations in this field.

THE MT. CARMEL CASE STUDY

In 1972 the Technion's Center for Urban and Regional Studies conducted two extensive surveys aimed at forecasting the demand for outdoor recreation activities at Mt. Carmel National Park (Enis and others 1974). Mt. Carmel National Park is the largest national park in Israel, located in the central and southern sections of Mt. Carmel, at the northern part of Israel, extending over some 20,000 acres. The study was also aimed at determining the recreational capacity of the park, and the formulation of a planning policy for the future development of the area.

Except in an extensive study by Coppock (1971), we had not come across a study which attempted to compare the two interview methodologies on a basis of actual large-scale investigations. Even in the aforementioned study, the analysis was mostly descriptive and the role of statistical analysis rather limited.

The home interview was conducted in 1972 and concerned recreation activities of the population during the preceding 12 months. In the study, 1938 households were interviewed, representing a 0.5 percent sample of the urban population in Israel. In each household, one of the adults 20 years or older was randomly selected for the interview. In most cases, this was the head of the family or his spouse. The interview was conducted in the interviewee's home.

The on-site interview was conducted on three representative dates: a mild winter weekend, a spring weekend, and a non-religious holiday (Independence Day).[1] Each date was considered a stratum, and the sampling rate in each stratum was 2 percent. Altogether, 845 recreationists were interviewed, each interviewee representing a recreation unit, i.e., visitors who arrived to the site as a group (e.g., a family). The interviewee was selected from among the adult members of the group. The interviewers were stationed in the parking lots of the major attraction sites in the park. In addition to the survey, throughout the day a count was made of all vehicles entering the park at its four access points in 30-minute intervals.

The two questionnaires contained as far as possible identical questions. However, the home interview included questions aimed at the sub-population which had not visited the park during the 12 months prior to the survey, and included more detailed questions dealing with the demographic and socio-economic background of the interviewee and the household. The site questionnaire, on the other hand, was more detailed in respect to questions dealing with recreational patterns within the park boundaries. Since the park offers no camping facilities at the moment, all visits started and ended within a period of about 12 hours.

RESULTS

The two surveys were compared on the basis of the estimates yielded by each for the following key variables: (a) total visitor-days, (b) frequency of visits, (c) range of recreational activities, and (d) measures of recreation benefits.

Visitor-Days

Both interviews enabled us to derive direct estimates of total visitor-days (or, alternatively, visit rates) broken down by origin, socio-economic characteristics, season of the year in which trips are concentrated, and so on. In the home interview, however, these estimates are calculated on the basis of the information contained in the sample <u>only</u>,

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[1] Observant Jews do not travel on the Sabbath and religious holidays and thus are not represented in surveys conducted on such dates.

and--apart from statistical error--they constitute reliable estimates of the relevant variable. Using the sample information on the number of visits per recreation unit and the size of each unit (usually a household), I estimated the total number of visitor-days between 800,000 and 1,070,000 during the 1971-2 season.

The site-survey related estimates were based on counts of vehicles entering the site, and the average number of occupants per car. In addition to the counts on representative dates, it was necessary to allocate the entire recreation period to each of the categories represented by these dates. This was done on the basis of the weather conditions prevailing during the season, as well as factors such as school vacations and religious holidays. Calculations yielded an estimate of 836,000 visitor-days, which falls within the interval of the home-survey estimate, albeit very close to the lower level. The site-survey estimate involves a number of supporting assumptions which are not required in the case of the home survey. In spite of this, however, the site survey yielded an independent estimate which would serve satisfactorily in most applications.

Frequency of Visits

The two surveys showed the effect of various socio-economic factors on the number of visits per recreation unit per year (table 1). The statistical tests for the significance, as well as the intensity, of the relationships between the variables were χ^2 and Cramer's V, respectively. The level of significance for the χ^2 test was $\alpha = 0.05$, and the critical value for Cramer's V was set at 0.125. Since V lies between 0 and 1, a lower value of V indicates a weak relationship, and a value closer to 1 a strong one (Blalock 1972).

The results of the two surveys are quite similar qualitatively. The only discrepancy exists with respect to car ownership, but this is explained by the fact that the population of the Mt. Carmel Park visitors is much more homogeneous with respect to car ownership than the corresponding population in the home interview.

A regression analysis of the frequency of visits data yielded similar results. The most significant factor affecting this variable was travel time. Since the mathematical forms underlying these regressions were different--a linear form in the case of the home survey and an exponential one in the case of the site survey--the coefficients of the travel time factor are not directly comparable. However, the elasticity (denoted by E) of the dependent

Table 1--Effect of socio-economic factors on the frequency of visits, Mt. Carmel National Park, Israel.[1]

Factors	Site survey	Home survey
Origin (place of residence)	++	++
Country of birth	0	0
Age of youngest child	0	0
Age of interviewee	0	0
Car ownership	0	+
Occupation of head of household	0	0

[1] 0 = there does not exist a significant relationship between the variables, i.e., $\alpha > 0.05$.

+ = $\alpha < 0.05$ and $V < 0.125$.

++ = $\alpha < 0.05$ and $V > 0.125$.

variable (frequency of visits) and the independent variable (travel time) is a convenient standardized expression for comparing the two models. If the dependent variable is denoted Y, and the independent variable X, exponential model becomes

$$E = \frac{\partial Y}{\partial X} \cdot \frac{X}{Y} = 0.519\ X$$

and linear model becomes

$$E = \frac{\partial Y}{\partial X} \cdot \frac{X}{Y} = \frac{0.957\ X}{Y} = 0.479\ X$$

when Y is evaluated at the mean ($\bar{Y} = 2.0$) of the sample. The results are strikingly similar, again--recalling the independence of the two data bases--substantiating our confidence in the site data.

Range of Recreational Activities

A high degree of correspondence was found between the results of the two surveys with respect to the popularity of various recreational activities (table 2).

Measures of Recreation Benefits

Various methods for estimating recreation

Table 2--Percentage of respondents who indicated a specific activity was the main one in which they engaged during their visit to Mt. Carmel National Park, Israel.

Activity	Site survey	Home survey
Picnic	67.5	51.2
Walking for pleasure	21.4	29.8
Driving for pleasure	6.6	12.9
Hiking	1.2	1.7
Sports, games	2.7	1.2
Photographing, painting	0.5	2.2
Other	-	1.2
	100.0	100.0

benefits have been proposed and applied (see, for example, Burton and Fulcher 1968). Briefly, there are essentially two methods for estimating recreation benefits. One is the Hotelling-Clawson approach in which we derive a demand schedule for the site, based on visit rates from several origins. From this schedule we calculate the consumers' surplus, which is a monetary measure of recreational benefits. Alternatively, we approach recreationists directly, and elicit from them their own valuation of benefits in terms of their willingness to pay for the recreational services involved. Theoretically, both methods should yield identical values. Also, both can be used in conjunction with either survey. The results of the willingness-to-pay approach is first described.

In each survey we queried the interviewees on their willingness to pay for recreational services in terms of an entrance fee (based on differential admission fees for adults and children), and--mainly for the purpose of a consistency test--in terms of their willingness to travel an additional distance to reach the park (because the authorities have decided to close an entrance). The responses in both surveys--including the time and money questions in each survey--were quite close, in spite of the emotional load inherent in such questions. (Presently, no entrance fees are charged.) The results are reported

Table 3--Cumulative percentages of respondents who indicated willingness-to-pay for recreational services, by measure of willingness, Mt. Carmel National Park, Israel.

In monetary values[1]	Site survey	Home survey
	- cumulative percentages -	
5.00	11.8	6.0
3.00	18.4	15.5
2.00	31.9	31.8
1.00	50.8	52.1
0.50	61.0	63.5
0.00	100.0	100.0
In terms of additional driving time (minutes)		
60	53.1	41.1
30	81.3	74.8
15	93.5	92.0
0	100.0	100.0

in terms of cumulative percentages for the obvious reason that a person who is willing to pay a certain fee will certainly be willing to pay a lower fee for the same service (table 3). Needless to say that aggregate benefit measures based on these raw data (of course, after rather elaborate analysis) also fell within the same order of magnitude.

Of course, the site survey would not yield any data on the willingness to pay of those who had not visited the park. If these people are willing in principle to pay something as an "option value," the total benefit values for the site would change accordingly.

CONCLUSIONS

The results suggest that a decision in favor of a site interview can often be an efficient solution (in terms of the information obtained per dollar expenditures) and not just a result of limited budget and a "better than nothing" alternative.

Much information is obtained through home surveys based on representative samples of the entire population in comparison with the data

[1] (entrance fees, in IL.)

obtained through on-site surveys of visitors only. We think, though, that a comprehensive home survey on the consumption of outdoor recreation services should be conducted periodically, say every 10 years, preferably attached to some national survey of households. Such a tool, however, is not recommended for individual sites, existing or planned, where the much cheaper site interview would yield data of sufficient quality and informational content. These data, combined with that of the household survey, should suffice for forecasts of demand, use patterns, benefit estimates, and so on. It is, of course, imperative that the questionnaires of both surveys be consistent, whether with respect to content or background questions.

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Relative Value of Selected Outdoor Recreation Activity Areas

Joseph E. Hoffman, Jr.

Abstract--A problem for the public sector is deciding how their limited budgets should be spent to provide for which outdoor recreation areas. Since the market system is not available to allocate resources efficiently, some other method of determining relative value and allocating efficiency is needed. In this study visitors were asked how much they would be willing to pay to use activity areas, such as campground or swimming beach, within Willow River State Park, Wisconsin. A random sample of visitors provided a measure of the relative value of each activity area. Generally, the more developed areas, such as the campground, were considered the more valuable areas. The values were then compared against costs (value/cost) and an efficiency index was developed. This was done for both annual maintenance-operation costs and total annual costs (maintenance-operation costs plus 1/20 of development costs at 5 percent interest). The results show that the most efficient areas are the least developed ones and the least efficient ones are the most costly to provide. Either the agency has over estimated the value visitors receive from the more expensive zones or visitors do not appreciate the cost of providing them.

The public sector is responsible for providing many of the outdoor recreation opportunities available to the public. The problem is deciding how limited budgets should be spent to provide for which outdoor recreation experiences. Since the market system is not available to allocate resources efficiently, some other method of determining relative value is needed.

The purpose of this study was to provide for more effective and efficient planning and management of a state park. The specific objectives were first, to develop and use a method of measuring the relative value of recreation activity areas within a park (to visitors), and second, to relate these values with the costs of providing these areas. The resulting efficiency indexes, relating value to

cost, should indicate which activity areas are more or less efficient in providing for public enjoyment.

EXPERIMENTAL METHODS

The method developed to obtain visitor values of activity areas was willingness to pay. Visitors were asked to indicate how much they would be willing to pay to use each activity area. This expression provides a measure of relative value of each zone. Only a few studies have used the willingness-to-pay approach and these studies were essentially for an entire park and not areas within a park (Davis 1963, Glascock and Born 1971, Manning 1973, Randall and others 1974, Romm 1969, Sinden 1974).

All visitors entering the state park on 12 randomly selected days were given questionnaires and asked to return the completed form to the entrance station when they left. The rate of return on completed questionnaires was 51.5 percent.

The park studied was the 2520-acre Willow River State Park in west central Wisconsin, U.S.A. It is oriented around a reservoir formed by a dam originally built for hydroelectric purposes. It is one of Wisconsin's newest state parks, having opened for visitors in 1971.

Willow River State Park was separated into nine activity areas or zones (fig. 1). An activity area is a geographic area wherein certain activities are more likely to occur. The nine activity areas are: campground (72 units); swimming beach; picnic area and dam near beach; picnic area near boat landing; Little Falls Lake and boat landing; Willow River below Little Falls Lake (river corridor); north side of park (primitive area); south side of park (primitive area); and any other part of the park (not shown on map; the area upstream from the lake was accessible from public highways and users were not required to go through the entrance station).

RESULTS

The most valuable areas are the most developed zones, and the least valuable tend to be the least developed. The campground and swimming beach were the most valuable areas.

In 1974, the development costs for the park were approximately $710,000 while the maintenance-operation budget was $60,000. Total annual costs include maintenance-operation

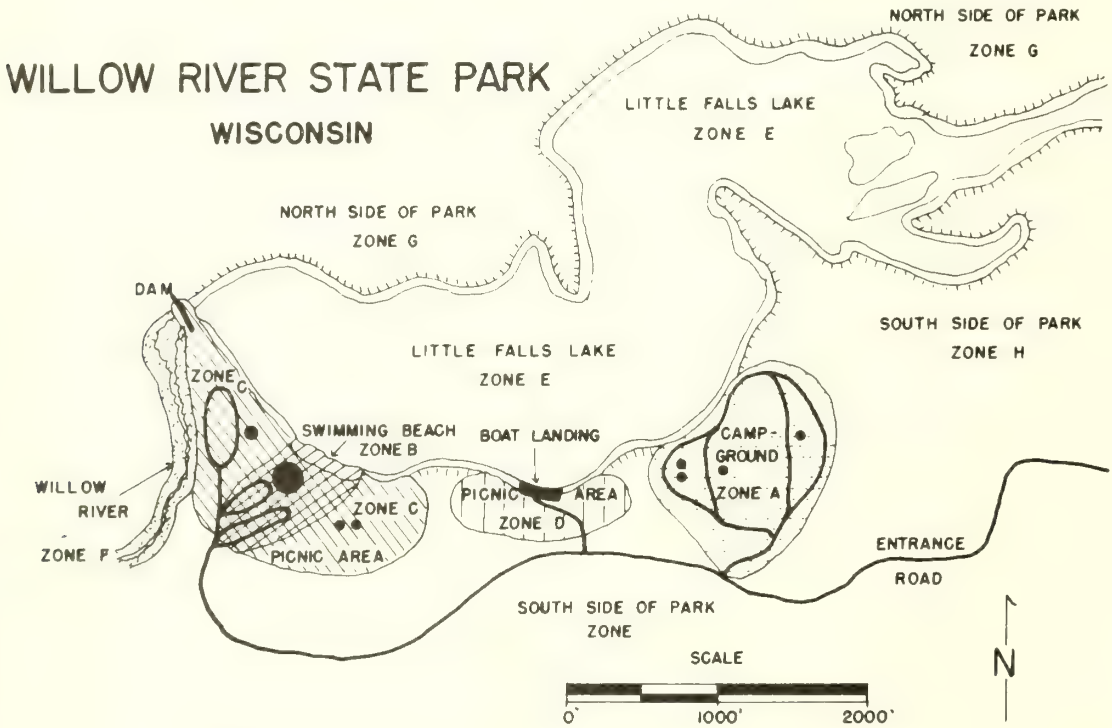

Figure 1--Willow River State Park in Wisconsin was separated into nine activity areas or zone for study.

Table 1--Efficiency indexes relating willingness-to-pay values to maintenance and operations costs, Willow River State Park, Wisconsin, summer, 1974, by activity area.

Activity area	Sum of dollar values[1]	Maintenance-operation costs[2]	Efficiency indexes[3]	Efficiency rank
Campground	727.11	$23,226	3.13	7
Swimming beach	331.03	9,678	3.42	6
Picnic area and dam near beach	230.29	8,710	2.64	9 (low)
Picnic area near boat landing	129.97	4,836	2.69	8
Little Falls Lake and boat landing	172.55	3,870	4.46	3
Willow River below Little Falls Lake	135.39	1,936	6.99	1 (high)
North side of park	127.21	2,904	4.38	4
South side of park	114.52	2,904	3.94	5
Any other part of park	122.73	1,936	6.34	2
	2,090.80	60,000	3.48	

[1] Based on 353 questionnaires and dollar values visitors said they were willing to pay.

[2] Overhead costs allocated back to each area based on the percent of development costs directly attributable to each zone.

[3] Value/cost times 100.

costs plus annual development costs based on a 20-year life and 5 percent interest. The campground, swimming beach and the two picnic areas are the most costly areas to provide. The river corridor and primitive areas are the least costly to provide (tables 1, 2).

The two efficiency indexes measured value over both maintenance-operations costs and total annual costs (tables 1, 2). The two picnic areas were the least efficient for the maintenance-operation cost indexes, while the swimming beach was the least efficient for total annual cost efficiency indexes. The most efficient area on both sets of indexes was the Willow River below Little Falls Lake area.

DISCUSSION

The purpose of developing efficiency indexes is to guide decisionmakers in the allocation of the resources at their disposal. The indexes indicate where resources could either be shifted between or withheld from activity areas or both to equalize the value/cost ratios. For the park manager the maintenance-operation cost indexes would be more useful, while the total annual cost indexes would be more useful to the park planner.

An example of how management could use efficiency indexes based on value/maintenance-operation costs is illustrated here. The most efficient zone is Willow River below Little Falls Lake with a ratio of 6.99. If this zone is adopted as the standard for efficiency, then the maintenance-operation costs of the other activity areas should be reduced until their efficiency ratio equals 6.99. If this was (or could) be done, then the maintenance-operations budget required would only be

Table 2--Efficiency indexes relating willingness-to-pay values to annual and development costs, Willow River State Park, Wisconsin, summer, 1974, by activity area.

Activity area	Development costs[1]	Annual development costs[2]	Total annual costs[3]	Efficiency indexes[4]	Efficiency rank
Campground	$257,510	$20,663	$ 43,889	1.66	7
Swimming beach	272,602	21,874	31,552	1.05	9
Picnic area and dam near beach	148,976	11,954	20,664	1.11	8
Picnic area near boat landing	2,752	221	5,057	2.57	6
Little Falls Lake and boat landing	12,296	987	4,857	3.55	4
Willow River below Little Falls Lake	0	0	1,936	6.99	1
North side of park	0	0	2,904	4.38	3
South side of park	16,396	1,316	4,220	2.71	5
Any other part of park	392	31	1,967	6.24	2
	$710,924	$57,046	$117,046	1.79	

[1] Overhead costs allocated back to each zone based on the percent of development costs directly attributable to each zone.

[2] Based on 20-year life span; and capital recovery multiplier = $[i\ (1 + i)^n]/[(1 + i)^n - 1]$, and 5 percent interest.

[3] Annual development costs and maintenance-operations costs.

[4] Value/cost times 100.

$29,899, a saving of $30,101 over the 1974 budget.

Another approach would be to shift funds from the more efficient areas to less efficient areas. The average maintenance-operation efficiency index was 3.48. All areas with ratios higher than this would lose funds to the areas with efficiency indexes lower than the average. This approach would allow for improving the lower ranked areas at the expense of the higher ranked areas.

Decisionmakers must realize that any budget allocation change may result in a different opportunity being provided. Some visitors may become discouraged and either derive lower values or stop using activity areas. Others may be encouraged to start using areas or may derive even higher values. But this change may result in a new mix of values being given, and the original value measurements may no longer be valid.

CONCLUSIONS

The most efficient areas are usually the least developed ones, especially when total annual costs are used in determining the efficiency ratios. This relationship indicates that visitors do not closely relate value with cost. Either the agency has overestimated the value visitors receive from the more expensive zones or visitors do not appreciate the cost of providing them.

This method, however, is not without its ›ssible limitations. The major one is the ›sumption that the relative willingness-to-›y values expressed by visitors is a valid ›asure. To verify this assumption would re-›ire an experiment in which user fees could › established for each activity area. Then ›e could be measured at the rate of different ›er fees.

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A Recreational Visitor Travel Simulation Model as Aid to Management Planning

Robert C. Lucas Mordechai Shechter[1]

Abstract--A simulation model for dispersed recreation areas has been developed that provides a means for experimenting with modifications of use or area conditions to determine effects on use patterns and encounters between visitor groups. The model, the results of a test of it, and potential future applications are discussed.

Numbers of people visiting most kinds of outdoor recreation areas continue to grow. This growth often creates problems for management, with the nature of the problems depending on the type of area and the management objectives established for it. In the United States, growth in use of dispersed recreation areas has been rapid (Lloyd and Fischer 1972) and the resulting problems of congestion and resource damage have been difficult for managers to solve. These problems have been particularly severe on lands established as wilderness. A wilderness, by law, is to be managed to permit natural ecological processes to operate without alteration by man and also to provide visitors with "outstanding opportunities for solitude."

Growth in the number of visits to wilderness increased about 15-fold from 1950 to 1975, threatening both natural ecosystems and the experience of solitude. Poor distribution of use, both in space and time, is common and accentuates the problems of congestion and eco-

[1] Dr. Shechter was affiliated with the Resources for the Future, Inc., of Washington, D.C., at the time work described in this paper was done.

system damage. Studies of the distribution of wilderness use show that very uneven use patterns are the general rule; use is heavily concentrated on certain portions of each area, while larger portions receive little use. Similarly, a few summer weekends usually experience sharp peaks in use. Redistribution of some use seems to offer considerable hope for reducing the adverse effects of heavy use.

Research has shown that visitor satisfaction is influenced substantially by the types of encounters with other visitors and that visitors report strong preferences for low levels of encounters (Stankey 1973). Therefore, managers of wildernesses receiving heavy use are beginning to take actions to modify or control use. In the United States, both the National Parks and the National Forests are rationing use of some areas. In some cases, this is done by limiting the numbers of visitors permitted to enter each day at various access points. In other areas, managers set nightly capacities for all camping areas and require visitors to establish and adhere to rigid itineraries that will not result in the campsite capacities being exceeded. If this restriction is impossible, the party is not permitted to visit the area at that time. In a few other areas, managers have attempted to influence visitors to voluntarily shift their use to other areas or times through educational pamphlets and personal contacts.

However, all the managerial actions, except the establishment of rigid itineraries (which have other problems discussed below), suffer from a major flaw. The manager's objective is to reduce use at overused locations, and to avoid excessive levels of various types of encounters (on trails, at campsites, etc.). However, there has been no way to relate changes in total use or redistribution of use to the number of encounters per party or to the amount of use of particular places within a wilderness. The complexity of travel routes, which characteristically overlap and intertwine, and the variability in travel decisions are so great that neither intuition nor analytic solutions are useful predictors of the variables of interest for a given amount of use.

The rigid itineraries do provide a more determinate result, at least for use of key locations and encounters between camping parties, but not for encounters between parties while traveling on the trails. For many reasons (weather, illness, over-ambitious planning, etc.), not all parties adhere to their itinerary, so results are not as determinate as they seem. More important, such close control of movements seems to detract from the visitors' experiences of adventure, exploration, and spontaneity, and to transplant the structure of modern urban life to the wilderness setting intended to offer release from civilization's pressures. In general, research has indicated that a desire to escape civilization is a major motivation for wilderness visits. Furthermore, most visitors feel assigning itineraries is a highly undesirable approach to use control (Stankey 1973).

If use pressures and encounters resulting from any given use level and pattern cannot be predicted, experimentation through trial-and-error is an apparent alternative. However, trial-and-error is not an effective approach. It is very time consuming; managers would have to try a policy for a year or more to see how it worked. Results for any one year could be heavily influenced by uncontrolled outside factors, such as weather. Detailed information on use patterns and encounters would be available only if special studies monitored the area. It would not always be possible to create the use pattern the managers desired to test. For example, if managers wanted to know the effect of a doubling in use, there probably would be no practical way to cause this much use in the short run. At least three sorts of high costs could also result from a trial-and-error approach to use management. First, serious long lasting or even irreversible damage to resources might result from tests of heavy use. Second, many visitor benefits could be sacrificed, either through testing excessive use levels that seriously reduced the quality of visitors' experiences or through testing low levels of use that resulted in many people being denied entrance. Finally, frequent, major changes in use policies could lead to controversy and severe public relations problems.

Systems that are too complex for analytic solutions and not suited to real-world experimentation are often approached by simulation modeling (Shechter 1971). Therefore, a wilderness travel simulation model was developed to provide a better way to formulate and evaluate use management policies. The simulation model provides a practical way to test use patterns quickly. Variability in visitor behavior is incorporated in the model, but, in just a few minutes, use can be simulated for an entire season or a number of seasons. The model records and displays in appropriate formats all the desired information on use and encounters. Because the experimentation takes place in the computer instead of the real world, we avoid the high social costs. Even the most extreme patterns can be tested without damage to precious resources.

Travel simulation models are common, but the requirements for the wilderness model were quite different. In particular, the interest

ı encounters was unique. Therefore, the ıited States Department of Agriculture, For-.t Service, entered into a cooperative re-ıarch agreement with Resources for the Future ıc., complementing ongoing research at RFF, ı develop a general use simulation model for lderness-type areas. Resources for the Fu-ıre involved specialists from International ısiness Machines, Inc. in the project.[2] The ıdel has been developed, modified and re-ned, and has been field tested.

This paper describes the model and re-ılts of the field tests, and presents conclu-'ons about future applications.

SIMULATION MODEL

All simulation models are simplified ab-:ractions of complex, real-world processes. ›wever, the wilderness travel simulator quite ıalistically embodies the main characteristics ' wilderness visitor movements and interac-'ons.

The computer program for the model gener-:es data on visiting parties who arrive at the 'ea at various simulated dates and clock imes, enter at particular access points, se-ıct routes of travel, and move along these ›utes. The simulated parties may overtake and ıss slower parties moving in the same direc-ion (overtaking encounters), pass parties mov-ıg in the opposite direction (meeting encoun-ırs), or pass by parties camped in areas visi-e from trails or other travel routes, such as ivers (visual encounters). Parties that stay /ernight select campsites which they may or ıy not share with other camping parties (camp ıcounters are recorded when they occur). On ı ensuing day, camping parties leave the ımpsite and continue on their chosen routes, ıd eventually leave the area.

The model consists of four important com-›nents:

1. Route network--This consists of entry ›ints, segments of trails or other travel ›utes, and camping areas.

2. User characteristics--Simulated par-ies have been differentiated by size and ıthod of travel (hiking or horseback in one application and by boat type in another). Arrival timing patterns, travel speed, etc., can vary depending on the type of party.

3. User-route interactions--Route selection can vary between party types, as can travel time in each direction over different trail segments.

4. User-user interactions--These are the three types of encounters described above.

To make the model operational, data are needed on the area and its use. The travel network must be known, and something about how different types of visitors behave within it--their patterns of arrival, various routes followed and relative popularity of each, travel speeds, and so on. This information is supplied to the model in probabilistic terms.

The simulator provides detailed output information for each individual simulation of a particular use situation or "scenario." Since part of the input data is of a probabilistic nature, the model has the facility of producing summaries of a series of replications of any such "scenario," providing average values of various performance measures, such as the amount, character, distribution, and timing of use. For example, the number of parties of each type using each trail segment is provided (if desired, even on a daily basis in one of the three versions of the model). Additional information is available on the number of encounters by type of encounter, by type of party (classified by mode of travel or by length of stay), and by individual trail segments and campsites (again, in one version, on a day-to-day basis).

The model is coded in the IBM-originated language GPSS (General Purpose Simulation System), version V. The model to date had been successfully operated on IBM's 360 and 370 series of computers as well as Control Data Corporation's 6600 computer. A version adapted to the Univac 1108 computer should be completed soon. A User's Manual (Shechter 1975) is available.

RESULTS OF FIELD TESTS

The model has been field tested in two areas: the Desolation Wilderness on the Eldorado National Forest in California, and Dino-

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Dr. Kerry Smith of Resources for the Future ıd David Webster and Norman Heck of IBM con-:ructed and programed the original version of ıe model. Dr. John V. Krutilla of Resources ›r the Future initiated the project and he, ıith, Dr. Charles Cicchetti, and Dr. Anthony isher all contributed to the initial concep-ıalization. See Fisher and Krutilla 1972; ıith and others 1974; Smith and Krutilla 1974.

[3] Single copies are available from Robert C. Lucas, Forestry Sciences Laboratory, Drawer G, Missoula, MT 59801, U.S.A., until the manual and all programs become available from the National Technical Information Service, United States Department of Commerce, 5258 Port Royal Road, Springfield, VA 22151, U.S.A.

saur National Monument (a National Park Service area) in Colorado and Utah.[4] The Desolation Wilderness is a high, mountainous, lake-dotted area of about 26,000 hectares, that is very heavily visited.[5]

The Green and Yampa Rivers in Dinosaur National Monument are fast-flowing, "whitewater" rivers that visitors float in boats, kayaks, and rafts. Use is much lighter than in the Desolation Wilderness.

Special sample surveys provided the needed input information on use and visitor behavior. In the Desolation, visitors kept travel logs, while in Dinosaur, visitors and professional boatmen on commercially guided trips kept logs to supplement National Park use data. In both studies, information was recorded on encounters.

In both areas, the first scenario was the existing situation, or "base case." One week of peak use was simulated. A 1-week initialization period achieved a realistic starting condition. Simulation results were compared with data from the user surveys as one check on model validity, both for use patterns and encounters. Agreement was good, particularly in Dinosaur National Monument, where more precise information on use characteristics and travel routes was collected and used in the model. In the Desolation, encounters were, for a variety of reasons, somewhat higher according to the model than reported by visitors. Several minor simplifications or departures from reality had compounded effects, but probably the most important reason was that the limited number of visitor travel routes used in the model (210 different routes) fell short of reflecting how variable visitor movements really were. As a result, slight over-concentrations of parties increased encounters. On the rivers, where there were fewer entry points and possible variation in routes was less, the problem was less severe.

Next, a variety of scenarios were tested. Use was increased and decreased by varying amounts, and uneven distributions were made more even by shifting use from popular entries to less-used access points, and from heavily used weekends to weekdays.

Some clear relationships, not all expected, emerged. Changes in total use (all other things remaining the same) produced proportionate results. That this would be true for use patterns is probably obvious; if total use doubles, use of nay specific location doubles on the average. Encounters, expressed in per-party-per-day terms, also would double in this example--something not entirely expected.

This predictable, proportional relationship provides a convenient base for comparing results of more complex scenarios in which use is redistributed with an across-the-board change with the same total use. The use-redistribution scenarios produced lower average encounters per-party-per-day than the same total use without redistribution. This was especially true for trail encounters (up to one-third fewer encounters than comparable across-the-board total use). Camp encounters dropped only a little below comparable unmodified use, presumably because campsites were somewhat limited, and most parties camped in about the same areas out of necessity even though they arrived by different routes or at different times.

Average encounters do not tell the whole story, however. The frequency of extreme encounter levels (very high levels, especially, but sometimes also very low and zero levels) changed substantially. A manager probably would be more concerned about reducing or eliminating experiences of unsatisfactory quality than altering averages. In addition, changes at key trouble spots were even more pronounced. This would also probably be more relevant to a manager's evaluation of the results of a scenario than overall averages.

POTENTIAL APPLICATIONS

We conclude that the simulator is a useful tool for the manager of a wilderness or similar area. The model does not, of course, make decisions for the manager. It does, however, allow him to compare carefully the likely results of various possible alternatives before he decides to implement a management plan. This makes it much more likely that the plan chosen will achieve management objectives and that public benefits will be maximized.

It also appears to us that it provides a practical way to achieve desired conditions in terms of the amount of use of key areas and in the quality of visitor experiences in terms of

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[4] The application to the Desolation Wilderness was a joint venture of USDA Forest Service Research and National Forest managers and Resources for the Future, including the present authors. The Dinosaur National Monument application involved the National Park Service, Dr. David W. Lime of Forest Service North Central Forest Experiment Station, St. Paul, Minnesota, and Professor Stephen F. McCool, Utah State University, Logan, Utah. A paper by McCool and Lime, "The Wilderness Area Travel Simulator: Applications to River Recreation Management," 1976 is available from them.

[5] A manuscript describing the results of the Desolation Wilderness application is being prepared.

estion or solitude but without requiring
t control of visitor itineraries.

We feel that the simulator should be applicable to many other sorts of dispersed recreation systems besides U.S. wilderness. In, we suspect imaginative applications to very different situations might be possible and useful. The elements in the model are ectly general. For instance, what we have d "trail segments" are, in general, "transation linkages" and could represent any of movement; for example, traffic on park ls or bicycle paths. The model provides six types of "transactions" (the general term for the entities whose behavior is ulated). We have usually named them large, um, or small hiking or horseback groups of itors, but any designation is possible. haps one type might even represent some of wildlife (say, elephants) if their ement could be described in probabilistic ns, and "encounters" would become "wildlife ervations," and the managers' goal might be increase, rather than decrease, encounters.

Certainly, the model is clearly applica- to any type of dispersed recreation area re visitor flows are of concern, where re are capacity constraints, where visitor ounters are significant, and where it is ired to allow visitors substantial freedom move about flexibly. In such situations, model is particularly well-suited to manment planning to modify use, that is, to er numbers of visitors entering at differ- places and times. The model can also be d to test effects of alterations within the a, such as new access points, closure of e travel routes, addition of campsites, and on. However, to simulate such changes, a is for specifying how visitors will respond the new conditions is needed. Observation current behavior cannot directly provide s basis, and other kinds of special infor- ion or assumptions based on expert judgment ld be required.

The use of computer-based simulation modng in outdoor recreation management plang may arouse fears of depersonalization. the contrary, it may help make it possible maintain the traditional values of recreanal visitor independence, flexibility, and ntaneity as well as to protect resources preserve the quality of experience in the e of growing demands on limited resour--s.

ZUSAMMENFASSUNG

Es wurde ein Simulationsmodell für streut liegende Erholungsgebiete entwickelt ches die Möglichkeit bietet mit veränderten zungen oder Verhältnissen im Gebiet zu experimentieren mit dem Ziel Auswirkungen auf Verwendungsart und Zusammentreffen von Besuchergruppen bestimmen zu können. Das Modell, die Ergebnisse der Modell-tests unc künftige Anwendungsmöglichkeiten werden besprochen.

RESUMÉ

Un modèle de simulation du comportement des usagers de sites de loisirs donnant des façons d'expérimentations avec les modifications dues aux diverses utilisations ou aux conditions de terrain permettant de déterminer des patterns d'usage et de rencontres entre groupes d'usagers a été mis au point. Le modèle, les résultats du test afférant et ses futures applications possibles sont en discussion.

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A Survey of Wildlife-Related Recreation in the Tennessee Valley Region

John L. Mechler E. Lawrence Klein

Abstract--This paper is designed to help planners and administrators better understand expenditures for wildlife-related recreation. Total spending generated by participants in a particular region is considered. In addition, potential benefits that might accrue to the local economy by increasing or enhancing wildlife-related recreation opportunities, or both, based on consumer-related preferences are outlined. An analysis of what people are seeking in terms of types of wildlife-recreation and the satisfactions gained can lead to planned wildlife development that will have a positive monetary impact at a local level.

The primary purpose of this paper is to examine the total spending and the spending patterns of wildlife-related recreationists in a particular region of the United States. A secondary purpose is to examine the preferences of these individuals in regard to hypothetical situations involving more intensive management of wildlife habitat and development of additional facilities.

The data utilized for this paper were taken from a major study of the monetary values and benefits of wildlife-related recreation demands in the Southeastern United States in 1971 (Horvath 1974a, 1974b). This study was sponsored by member states of the Southeastern Association of Game and Fish Commissioners, the U.S. Forest Service's Region 8, and the Tennessee Valley Authority. A forthcoming publication by the Environmental Research Group at Georgia State University will present these findings and draw conclusions regarding the value of wildlife-related recreation. It should be stressed that it is not the intent of this paper--nor is it recommended--that the results be interpreted to reflect necessarily on the economic evaluation of wildlife-related recreation.

The results are strictly intended to contribute toward a better understanding of wildlife-related recreation, the total spending generated by participants in a particular region, and some potential benefits that might accrue to local economies by increasing and/or enhancing their wildlife-related recreation opportunities based on consumer-stated preferences. For example, planners and administrators at the local level are frequently interested in the potential monetary impacts that might result if a greater number of wildlife recreationists were attracted to their area. The results of this paper can serve as initial input into that decision process.

The gross expenditures of selected recreation groups have frequently been used for this purpose and not without good reason. The amount of money spent by these groups can in fact represent a direct increase to the flow of money within an economy (Crutchfield 1962). Examples of wildlife-related studies include Wallace (1956), Utah State Department of Fish and Game (1957), University of Utah (1960), Kirkpatrick (1965), Thompson and others (1967), and Nobe and Gilbert (1970) to list a few. Although such studies have been criticized by economists as being of little value in solving actual valuation problems (Wennergren 1967, Kalter 1971), they have been used by planners and administrators to a great extent. In short, they have been applied for over 20 years with generally good results while economists continue to attack the lack of rigor and continue their debate over an acceptable method.

Gross expenditure studies, however, cannot show the extent of impact that recreation expenditures have on local or regional economics. Variations in factor endowments, social and political infrastructures, total economic composition, cyclical natures of various types of industries, and other variables influence the degree of impact that gross expenditures have in different locales.

Input-output studies have been shown to be very valuable in examining this degree of impact and for planning the utilization of the resources of a region and its economic development (Isard 1960). An example of a wildlife-related input-output study in one county of Colorado is the one by Rohdy and Lovegrove (1970). They determined both the primary economic effects of gross expenditures of hunters and fishermen as well as the secondar economic effects of these original expenditures within the local economy. Their ap-

ch is more useful for detailed planning, it is also more expensive; Rohdy (personal unication 1975) estimated that a similar y in one county would require approximate- 100,000 to complete. Obviously, this is a e investment and one that would not be rtaken without some prior assessment that tential payoff might exist. Gross expend- e studies can help in making this prior ssment.

A particular area covered by this paper he Tennessee Valley region, a 41,000- re-mile area in the Southeastern United es composed of portions of seven states.

EXPERIMENTAL METHODS

The primary data were collected by house- l interviews, mostly in April and May 1972, he Environmental Research Group at Georgia e University. The sample was composed of 76 households selected from the 1,246,168 seholds in the Tennessee Valley region. a were obtained on various socio-economic racteristics of the members of households icating participation in wildlife-related reation activities.

Three major wildlife-related recreation ivities were selected for the study. These hunting, fishing, and nonconsumptive wild- e use. Each of these was further subdivid- into three categories resulting in nine cific wildlife-related recreation activi- s. These are:

1. Saltwater fishing
2. Warm freshwater fishing
3. Cold freshwater fishing
4. Small game hunting
5. Big game hunting
6. Waterfowl hunting
7. Watching or photographing birds
8. Watching or photographing animals
9. Watching or photographing aquatic life

Questions were also asked of participants arding the physical characteristics of rec- tion areas which they considered important. ailed data were also sought from partici- ing households on both capital and variable enditures.

Sampling Methodology and Data Preparation

Horvath (1974b) provides a very detailed description of the sampling methodology and data preparation phases. The following is a summary of his description.

The procedure used to obtain a probability sample of households followed closely those procedures used by the United States Bureau of the Census for the monthly Current Population Survey.

Following these Bureau of the Census procedures permitted the use of the then-current groupings of counties within the Tennessee Valley region into essentially the same Primary Sampling Units (PSU's) used by the Bureau. However, some modification was required in order to ensure that certain of the PSU's as used by the Bureau were restructured so as not to cross the region's boundary. These PSU's were thus combined into several strata within the region in such a way that individual strata were wholly contained within the region. The criteria of heterogeneity within PSU's and homogeneity within strata of certain socio-economic characteristics of the population were the basis of groupings.

From each of the strata, one PSU was selected for sampling with probability of selection proportional to population size. The total sample of 1,076 households was allocated to each stratum proportional to population size. The strata samples were allocated to the selected PSU's and that sample proportionately reallocated among the constituent counties of the PSU's.

For each county selected to be in the sample, population and household information was determined for enumeration districts, block groups, and individual city blocks. The sources of this information were the census summary tapes and county maps from the Geography Division of the Bureau of the Census. A cluster of four households to be interviewed in each block was then marked on the maps based on the "northwest corner clockwise method" which is utilized in some agricultural surveys. Once these given households were selected to be in the sample, no substitution was permitted to replace those households from which responses could not be obtained, whatever the reason for the nonresponse.

The field interviewing was conducted by personnel of a national interviewing firm who received very detailed instructions concerning interview procedures. A 12-page questionnaire served as the source of the questions to be asked as well as the record of responses.

Capital Expenditures

Respondents were asked for dollar esti-

mates for current replacement costs of specific types of property and equipment used primarily for wildlife-related recreation during 1971. Fourteen categories were included in the questionnaire. These were:

1. Recreation vehicles including jeeps, all-terrain vehicles, swamp buggies, fishing cars, etc.

2. Motorcycles, motor scooters, bicycles.

3. Winter equipment including snowmobiles, snowshoes, etc.

4. Horses and riding equipment.

5. Motorboats, sailboats, houseboats, canoes, motors, etc.

6. Recreational land and/or water without improvements.

7. Cabins, cottages, travel homes, boat docks, and other improvements.

8. Campers and travel campers.

9. Camping equipment including stoves, lanterns, tents, etc.

10. Hunting equipment, such as guns, archery equipment, field glasses, etc.

11. Fishing equipment, such as rods, reels, nets, etc.

12. Special leases on land or water for hunting.

13. Special leases on land or water for fishing.

14. Diving gear used for underwater fishing.

The values utilized for capital expenditures are the annual depreciation costs of these items--not total replacement costs; each item was depreciated over a period applicable to that particular item (Horvath 1974a), except categories 6, 12 and 13. Category 6 was not depreciated or amortized, and, thus, a slight upward bias was introduced. The annual lease fees were utilized for categories 12 and 13.

Variable Expenditures

The variable expenditure categories included the following:

1. A per-mile cost assigned to the estimated number of miles driven for wildlife-related recreation in family cars and recreational vehicles.

2. Commercial transportation costs.

3. Lodging.

4. Food and refreshments.

5. Services connected with hunting, such as guides and equipment rental.

6. Services connected with fishing.

7. Services connected with nonconsumptive wildlife use.

8. Supplies for hunting, such as ammunition, clay birds, etc.

9. Supplies for fishing, such as hooks, line, etc.

10. User fees for facilities and access.

11. Hunting licenses.

12. Fishing licenses.

The total sample size included 1,076 households. Of these, 917 (85.22 percent) of the interviews were completed. Of the remaining interviews, 109 (10.13 percent) were not completed because the residents were not home, and 50 (4.65 percent) because of language barriers, illness, and refusals.

The total number of persons covered by the sample was 2,288--1,633 adults and 655 children. Of the adults, 1,472 were married and 161 were single. The children in the sample were 324 sons and 331 daughters.

RESULTS

The distribution of Tennessee Valley households by income categories is shown in table 1. Also included in table 1 is the estimated total Valley income for 1971 based on the median value for each income range, except for the first income category where an arbitrary value of $2,500 was used, and the last income category where an arbitrary value of $36,000 was used.

Income of households may or may not be a significant factor helping to determine whether or not to participate in wildlife-related recreation, but it would certainly seem to dictate the degree of participation in terms of total money spent, number of trips, and the types of activities selected.

ıle 1--Percentage composition of households, by income categories, in the Tennessee Valley Region in 1971 and the estimated total income received

Income ($)	Percent of households	Estimated total Valley income ($ thousand)
Under 3,001	22.9	$ 713,431
3,001 - 5,000	17.9	892,256
5,001 - 7,000	16.0	1,196,320
7,001 - 10,000	18.8	1,991,375
10,001 - 15,000	13.4	2,087,330
15,001 - 20,000	6.2	1,352,091
20,001 - 25,000	2.7	757,046
25,001 and over	2.1	942,102
Total	100.0	$9,931,951

The percentage of participation of house-lds, by income categories, in the three jor wildlife-related recreation activities--nting, fishing, nonconsumptive activities--ried according to activity (table 2).

Tennessee Valley households with incomes $5,000 and less were generally represented all the three major activities to a smaller gree than were households with incomes eater than $5,000.

Tables 3, 4 and 5 summarize the number of useholds and percentages of total households th one or more members participating in nting, fishing, and nonconsumptive wildlife tivities. Also included in each table are e specific activities comprising each major tivity.

The U.S. Department of the Interior, reau of Sport Fisheries and Wildlife (1972) und 18 percent of all households in the ited States participated in hunting activ-ies in 1970. Thus, the value of nearly 26 rcent of households in the Tennessee Valley gion would seem to represent a greater par-cipation rate. However, no attempt was made determine if a statistical difference ex-ted because of differences of when the sur-ys were completed and probably differences sampling techniques and definitions of tivity categories.

Again, by way of comparison, 34 percent of all households in the nation had one or more persons who fished in 1970 (U.S. Dep. Inter., Bur. Sports Fish. & Wildl. 1972), but for the same reasons as listed for hunting, no attempt was made to determine if the observed difference was statistically significant.

Table 5 shows the number and percentage of households with one or more members reported to be involved in nonconsumptive wildlife activities. Over 50 percent of these households reported that birds are the sole wildlife species of interest to them.

Table 6 shows the total expenditures made by households in 1971 on wildlife-related recreation activities as well as the percentage breakdown of households participating in wildlife-related activities. As shown, some households participated in more than one activity and also used some equipment for more than one activity. Therefore, all combinations of activities with the percentage of participating households and the total expenditures for each are shown.

The total expenditures of $211,311,000 (from table 6) represent 2.13 percent of the estimated total Tennessee Valley household income (from table 1) during 1971. A total of 47.7 percent of all households in the

Table 2--Percentage participation of Tennessee Valley households during 1971 in hunting, fishing, and nonconsumptive wildlife activities, by income categories

Income ($)	Percentage household participation in		
	Hunting activities	Fishing activities	Nonconsumptive activities
Under 3,001	13.3	23.6	5.4
3,001 - 5,000	22.0	35.2	6.9
5,001 - 7,000	33.8	43.7	6.3
7,001 - 10,000	29.9	49.7	11.4
10,001 - 15,000	34.5	53.8	12.6
15,001 - 20,000	32.7	47.3	18.2
20,001 - 25,000	29.2	50.0	16.7
25,001 and over	21.0	47.4	21.1
All categories	25.7	40.9	10.8

Table 3--Households participating in various wildlife hunting activities in the Tennessee Valley region in 1971

Types of hunting	Number of households	Percent of all households
Small game only	223,045	17.9
Big game only	23,718	1.9
Waterfowl only	1,425	0.1
Small and big	51,875	4.2
Small and waterfowl	6,177	0.5
Big and waterfowl	1,324	0.1
All three	12,785	1.0
Total hunters	320,347	25.7
Nonhunters	925,796	74.3

: 4--Households participating in various wildlife fishing activities in the Tennessee Valley region in 1971

Types of fishing	Number of households	Percent of all households
Saltwater only	10,306	0.8
Warm freshwater only	333,334	26.8
Cold freshwater only	59,429	4.8
Saltwater and warm freshwater	38,053	3.1
Saltwater and cold freshwater	11,195	0.9
Warm and cold freshwater	43,080	3.5
All three	14,183	1.1
Total fishermen	509,579	40.9
Nonfishermen	736,588	59.1

e 5--Households participating in various nonconsumptive wildlife activities in the Tennessee Valley region in 1971

Types of nonconsumptive wildlife activities	Number of households	Percent of all households
Bird only	71,032	5.7
Animal only	17,446	1.4
Fish only	1,246	0.1
Bird and animal	43,616	3.5
Bird and fish	1,246	0.1
Animal and fish	0	0
All three	11,216	0.9
Total nonconsumptive enthusiasts	145,802	10.8
Nonwildlife enthusiasts	1,100,365	89.2

Table 6--Total expenditures on all wildlife recreation activities and combinations thereof by households in the Tennessee Valley region in 1971

Activities	Percent of participating households	Total expenditures ($ thousand)
Fishing only	16.8	$ 64,361
Hunting only	4.3	5,431
Nonconsumptive activities only	3.0	8,412
Fishing and hunting	17.6	96,572
Fishing and nonconsumptive	2.5	11,919
Hunting and nonconsumptive	0.7	2,231
All three activities	2.8	22,376
Total	47.7	$211,311

Table 7--Percentage distribution of the total depreciated replacement value for capital items used for wildlife recreation by participating Tennessee Valley households in 1971

Capital items	Percentage
Recreational vehicles	14.4
Motorcycles, scooters, and bicycles	4.9
Winter equipment	0.1
Horses and riding gear	2.4
Boats, canoes, etc.	20.8
Cabins and other improvements	20.8
Campers, trailers	8.1
Camping equipment	4.4
Hunting equipment	13.5
Fishing equipment	9.3
Leases for land/water used for hunting	0.1
Leases for land/water used for fishing	1.1
Diving gear	0.1
Total	100.0

Table 8--Percentage distribution of the total variable expenditures for wildlife recreation by participating Tennessee Valley households in 1971

Expenditure category	Percentage
Mileage costs	22.0
Commercial transportation	1.4
Lodging	8.2
Food and refreshments	19.7
Services connected with hunting	2.0
Services connected with fishing	3.4
Services connected with nonconsumptive activities	0.9
Supplies for hunting	8.8
Supplies for fishing	25.7
User fees for facilities and access	1.8
Hunting licenses	1.7
Fishing licenses	2.3
Miscellaneous	2.1
Total	100.0

Table 9--Characteristics of quality hunting and fishing areas as reported by participating Tennessee Valley households in 1971

Characteristic	Weighted percentage importance	
	Hunting	Fishing
Available overnight facilities	6.7	7.3
Within convenient travel time	33.8	35.3
Abundance of animals or fish	30.3	30.6
Low participant density	15.3	13.9
Presence of trophy animals or fish	3.6	2.3
Appearance of area	10.2	10.6
Total	100.0	100.0

Table 10--Willingness to pay an extra fee for improved quality areas on public and private lands

Type of land	Hunting	Fishing (percentages)	Nonconsumptive
Public			
Yes	51.3	48.8	49.3
No	38.7	40.3	33.3
No opinion	10.0	10.9	17.4
Private			
Yes	49.3	43.6	41.3
No	37.3	41.4	36.6
No opinion	13.4	15.0	22.1

Tennessee Valley participated in one or more wildlife-related recreation activities during 1971.

The depreciated replacement value for all capital items utilized for wildlife-related recreation activities averaged $166 per participating household. This value included the nonamortized total value for recreation land and/or water. When adjusted for this bias by subtracting the investments in recreational land and/or water, the depreciated replacement value for all capital items totaled $155 per participating household (table 7).

The average variable cost per household participating in wildlife recreation activities was $200 (table 8).

Quality Preferences

Characteristics of hunting and fishing areas which participants regard as important should serve as useful guidelines for planners and administrators. Respondents in the participating households were asked about what constituted a quality hunting or fishing area. The most important determinant of both quality hunting and quality fishing areas is that they are within convenient travel time (table 9). Abundance of animals or fish is the next most important characteristic for both activities, followed by low density of people.

Most of the respondents expressed a willingness to pay an extra fee for hunting or fishing on lands that had improved qualities (table 10).

SUMMARY

Wildlife-related expenditures in the Tennessee Valley region totaled over $200 million in 1971. Although this represented only about 2 percent of the estimated total household income in 1971, it is nonetheless considerable amount of money which might be important in terms of enhancing the economie of some local areas.

Nearly one-half of all households in th Tennessee Valley region participated in one o more wildlife-related activities, ranging fr hunting and fishing to nonconsumptive activities. Fishing showed the greatest participation rate at nearly 41 percent; hunting was next at approximately 26 percent, followed b nonconsumptive activities at about 11 percen Both the hunting and fishing participation rates for Tennessee Valley households were higher than the national values for the same activities. This difference suggests that there might well be greater potential for wildlife-related development activities in t Tennessee Valley than possibly other areas where fewer people participate.

Even within each of the major activitie differences in the participation rate existe based on household income categories. It appears that $5,000 might be considered the threshold for hunting and fishing activities in that participation rates are greatest abo that figure. The threshold for nonconsumpti activities is $7,000. These figures suggest that the evaluation of wildlife-related devel opment potential would definitely include an examination of the incomes of user groups which might be attracted.

The participation rate varies within eac major activity also. For example, almost al the hunting activity was in the small game category, and over one-half of the fishing ac tivity was in the warm freshwater category.

ese differences are primarily reflective of e opportunities available for participation. is was also indicated in the nonconsumptive ea in which birds were the single greatest tegory. One could not contend that these tivities would justify a significant mone- ry development, since the reason they are ıst participated in is that there is more ıportunity to do so.

The most important characteristics that ːtermine a quality hunting and fishing area ·e convenient travel time and abundance of ıimals or fish. The least important charac- ːristics are overnight facilities and pres- ıce of trophy animals or fish. Thus, in any ːvelopment of a wildlife nature, it must meet ıe criteria of abundance and convenience to ttract the most visitors; but such amenities s overnight facilities and trophy animals and ish are not very important.

One factor that is very important to lanners and managers is that in all activi- ies, a majority of respondents were willing o pay an extra fee for improved quality areas n both public and private lands.

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Mathematical Programming in the Context of Planning for Multiple Goals

A. B. Rudra

Abstract--In attacking some forest management problems, multiple goals can be linked through a single performance-function criterion. A variety of such problems have been solved by traditional mathematical programing techniques, such as linear programing. But in another class of problems, such a unified single-dimension criterion is not readily available. Increased concern in environmental quality has emphasized the importance of extra-market benefits. Surrogate measures are often not adequate enough for assessing the totality of such intangible values that result from any activity. Infeasibility of solution is another difficulty encountered in the conventional structuring of multiple conflicting goals through linear programing. The goal programing approach is, therefore, advocated as ascertaining the trade-off in achieving specific goals. The approach is illustrated by a case study.

In recent years, the use of mathematical programing in forestry has undergone a sharp upsurge. The most commonly used technique is the linear programing (LP) formulation, either in the conventional way, or in one of its allied forms. Problems are generally structured in the usual product mix allocation and scheduling formats. Studies cover both the single-stage and the multistaged formulations. All such formulation seek to optimize a single-dimensional objective function criterion, while satisfying a set of constraints which define a number of intermediate goals.

This paper seeks to draw attention to the method of goal programing (GP) and, hopefully, to nudge the case for stochastic programing--techniques which do not appear to have been extensively used in forestry so far.

In the standard LP format, all activities are optimized in terms of a common performance function. Thus, if profit maximization is the goal, financial returns are assessed by discounted net revenue, present net worth, internal rate of return, benefit-cost ratio, or some such single criterion for all activities. Similarly some common measure of costs is used in the cost minimization case. However, in planning for multiple-use forestry, particularly when extra-market benefits are involved, it is not always possible to select a suitable criterion--for the comprehensive appraisal of the multi-faceted benefits that result from the activities--for consideration in the objective function.

Growing interest in environmental quality has highlighted the need for environmentally sensitive indicators rather than the usual economic indicators. Natural resources, such as forests, national parks, etc., are not readily subject to market valuations. This limitation has resulted in an increase in research into the evaluation of extra-market benefits. Certain proxy values have been proposed for the assessment of unpriced goods. In the field of recreation, for example, the use of consumer surplus shows considerable promise as a measure of the society's willingness to pay for an amenity. Even the inclusion of a surrogate measure to cover the inclusion of extra-market benefits into the objective function does not, however, overcome the problem of using market prices for the rest of the commodities in an economic planning exercise.

There are the problems of partial equilibrium models and although there is a definite trend towards general equilibrium models (Forsund 1972, Muller 1973) there is still inadequate econometric information to rely on. We must also emphasize that there is some controversy regarding the evaluation of extra-market benefits in part. Indeed, Schramm (1973) argues that it is impossible to evaluate all of the extra-market benefits and, therefore, one should not attempt to assess a fraction of them only. Johnston (1974) discusses some of the difficulties in deciding upon a suitable indicator of social economic welfare in environmental quality control.

It is important, therefore, to examine the trade-off between environmental and conventional materialistic goals--and goal programing provides a method for such analyses. A modification of standard linear programing, it obviates the need for a single dimensional optimization criterion. And by the very nature of its formulation, it removes the in-

f sibility of solution. In conventional LP, t lack of a feasible solution is often very f strating, as the offending constraints may n be readily apparent when the initial prob- l is structured.

Chance-constrained programing (CCP) is an e mple of stochastic programing. Constraint e ations representing the goals can be re- p ced by a measure of probability or risk of n achieving any or all of the constraints. T s removes the necessity that all con- s aints must be satisfied.

GOAL PROGRAMING

Lee (1972) recounts the history of goal gograming. The concept of GP was developed Charnes and Cooper and they also provided e name of the method (Charnes and Cooper 61). For a detailed exposition of the tech- que, consult papers by Charnes and others 968a, b; 1969), Ijiri (1965), Lee (1971, 72), and Field (1973).

The goal programing model sets out to nimize the aggregate sum of the positive and gative deviations from goals which are spec- ied by constraints. Thus the objective nction consists of coefficients for the de- ations of the goals and places no value for e structural variables depicting activities. may set out the GP model in the familiar LP rm as follows:

Minimize $\quad z = \underset{\sim}{c}'\underset{\sim}{d}$

Subject to $\quad \underset{\sim}{A}\underset{\sim}{x} + \underset{\sim}{I}\underset{\sim}{d}^{-} - \underset{\sim}{I}\underset{\sim}{d}^{+} = \underset{\sim}{b}$

$$x_j,\ d_i^-,\ d_i^+ \geq 0 \qquad (j=1,\ldots n;\ i=1,\ldots m)$$

$$\underset{\sim}{d} = \begin{bmatrix} \underset{\sim}{d}^{-} \\ \underset{\sim}{d}^{+} \end{bmatrix};\ d_i^- \,.\, d_i^+ = 0 \qquad (i=1,\ldots m)$$

additional group of constraints, not involv- ng the positive or negative deviations, may ometimes also be included to deal with rela- ons between the constraints.

here m = number of constraints or goals

n = number of decision variables

$\underset{\sim}{x}$ = column vector of decision variables (n elements)

$\underset{\sim}{A}$ = the matrix (m x n) of technological coefficients

$\underset{\sim}{I}$ = the identity matrix (m x m)

$\underset{\sim}{d}^{-}, \underset{\sim}{d}^{+}$ = column vectors of the positive and negative deviations from goals; each of the vectors has m elements

$\underset{\sim}{b}$ = column vector of m elements representing the goal levels

$\underset{\sim}{c}'$ = row vector representing the coefficients of the objective function; these are the weighted or unweighted priority factors.

One recognizes immediately the similarity between the deviation variables in GP and the slack variables in LP, in changing inequalities into equalities. The imposition of a positive and a negative deviation to each constraint or goal equation, removes the possibility of infeasibility. Further the formulation ensures that either d_i^+ or d_i^- will be zero The weighted priorities are given by $\underset{\sim}{c}$. Let u first consider the effect of minimizing differ ent sets of the unloaded deviates. Minimizinc $(d^- + d^+)$ makes the search for x which achieve the goal $\underset{\sim}{A}.\underset{\sim}{x} = \underset{\sim}{b}$, thereby minimizing the absolute value of $(\underset{\sim}{A}.\underset{\sim}{x} - \underset{\sim}{b})$. Minimizing only (d^-) results in minimizing the negative deviations from the goal. Solution gives x which sets $(\underset{\sim}{b} - \underset{\sim}{A}.\underset{\sim}{x})$ to the minimum possible. On the other hand, minimizing only (d^+) results in x which sets $(\underset{\sim}{A}.\underset{\sim}{x} - \underset{\sim}{b})$ to the minimum possible.

Several techniques are available to prescribe priorities and weights. And it is possible to force an ordering of the attainment of goals (Lee 1972, Field 1973). If no weighted priorities are used, then the elements of $\underset{\sim}{c}$ will all equal 1. We may ignore some of the deviations in which case these elements in c will have zero value. The loading scheme could be an artifact of the data base, or it could be subjectively prescribed. Such ad hoc weighted priority loads may be taken to represent either conventional wisdom or current thinking on the relative importance of goals. It would appear (see following examples) that the relative order of these loads is more important than actual value of these loads. Generally, as long as we give relatively large loads to the deviations we seek to avoid (i.e., seek to ensure the attainment of the goals concerned) these deviation variables will not appear in the final basic solution in a minimization scheme (compare the case of artificial variables in a normal LP scheme).

To further clarify the method, we first consider a simple problem. The corresponding LP and GP formulations are tabulated in figures 1 and 2. The details are self explanatory. For the GP case (fig. 2) we have first considered two unweighted priority schemes, and the last two schemes use ad hoc loads (03)

	X_1	X_2	RHS	Solution (Basic variables)
OBJ	80	40	(Maximize)	$X_1=24$
Constraints				
(1)	1	1	$\leqq 40$	$X_2=16$
(2)	1		$\leqq 24$	Slack of (3)=14
(3)		1	$\leqq 30$	OBJ = 2560

Figure 1--The linear programing formulation

	X_1	X_2	d_1^-	d_2^-	d_3^-	d_1^+	d_2^+	d_3^+	RHS	Solution (Basic variable)
										For 01 & 02
Objective Functions										$X_1=10$
										$X_2=30$
01			1	1	1	1	1	1	(Minimize)	$d_2^-=14$
02			1	1	1	1			"	
			P_1	$2P_2$	P_3	P_3-(weighted priorities)				For 03 & 04
03			1000	100	1	1			(Minimize)	$X_1=24$
04			985	82	1	1			"	$X_2=16$
										$d_3^-=14$
Constraints										
(1)	1	1	1			1			= 40	Min. aggregate of deviates
(2)	1			1			1		= 24	01=02=03=04
(3)		1			1			1	= 30	= 14

Figure 2--The general programing formulation

d weighted priorities calculated on the sis of some algorithm based on the problem ta. Cases (01) seek to Min $(d^- + d^+)$, the viations not being loaded. Case (02) is simar (ignores d^+ and d^+) to Cases (03) and (04), cept that (02) uses no weighted priorities. tice that a variety of solutions are possie, depending on the goal ordering scheme.

Let us now consider a simplified version a real life problem (fig. 3). A forest has ree zones A, B, and C. For each zone, three nagement alternatives are available:

TP = Area to be worked for timber production

R = Area to be exclusively used for recreation

MU = Area to be managed for multiple use, say recreation and limited timber production besides other amenities.

e goals that set standards for water quality e the constraints for biochemical oxygen dend (BOD constraint 4) and suspended solids S constraint 5). Permissible cut (V) is set constraint 6, while summer and winter tourt loads (ST and WT) are specified by conraints 7 and 8, respectively. Hypothetical ta have been used for this exercise (fig. 4). lues are in appropriate units for the riables concerned, but actual units are not ecified.

The GP model for the problem is given in g 5. Fig. 6 shows the solutions, with relent remarks.

In the LP solution of the problem, conraint 10 (Income) was removed and the coefcients of income constraint was used in the jective function (fig. 7). This solution r income maximization is provided for comrison. Note that all areas are selected for mber production only. The results incorpote a limited amount of sensitivity analysis way of ranging RHS (for nonslack resources) ld objective function (for basic variables).

The goal programing model provides a nge of solutions, depending on the pattern loads attached to the deviation variables. lese solutions help in deciding on trade-off etween various goals. They also help in iderstanding the extent of sacrifice involved forcing the realization of any sub-set of als.

STOCHASTIC PROGRAMING

The central idea of a stochastic program to convert the probabilistic problem into its equivalent deterministic form (Sengupta 1972). The chance constrained programing method (CCP) is one such technique, developed by Charnes and Cooper (1959).

Many of the parameters of most real-life problems are described by random variables rather than by deterministic quantities. Thus in the customary LP model [maximize $Z = \underset{\sim}{c}'\underset{\sim}{x}$, $\underset{\sim}{A}x \leq \underset{\sim}{b}$, $\underset{\sim}{x} \geq \underset{\sim}{o}$], the elements of the set $(\underset{\sim}{A}, \underset{\sim}{b}, \underset{\sim}{c})$ are generally stochastic. It is obvious that through random variations in Θ, where Θ denotes the vector with elements $(\underset{\sim}{A}, \underset{\sim}{b}, \underset{\sim}{c})$, considerable differences could occur in the solution. Partial answers are available, through standard sensitivity analyses in LP, to study the effect of changes in the problem parameters on the optimal solution. Stochastic programing considers these random effects more explicitly in the solution of the model.

In general, c_j, a_{ij}, and b_i are all random variables. If c_j is a random variable we could substitute its expected value, so that the objective function becomes [maximize $Z = \sum_{j=1}^{n} E(c_j).x_j$]. We will not consider the situation when both a_{ij} and b_i, in any constraint, are simultanteously random variables, and restrict ourselves to the simpler case of separately considering either a_{ij} and b_i only as random. When the linear constraints of a LP formulation are associated with probability measures indicating the extent of the violation of the constraints, the LP model is chance constrained. Thus the chance constraints could be expressed as:

$$\text{Prob}\left[\underset{\sim}{a}_i' \underset{\sim}{x} \leq b_i\right] \geq \beta_i \qquad (i=1,\ldots m)$$

stipulating that each constraint or goal is then realized with a minimum probability β_i, where $0 \leq \beta_i \leq 1$. These restrictions imply an equivalent set of linear inequalities

$$\underset{\sim}{a}_i' \underset{\sim}{x} \leq B_i \qquad (i=1,\ldots m)$$

which are the deterministic equivalent constraints, B_i is the largest number satisfying

$$\text{Prob}\left[b_i \geq B_i\right] \geq \beta_i$$

or equivalently

$$\text{Prob}\left[b_i < B_i\right] \leq 1 - \beta_i$$

where the number B_i is the $(1 - \beta_i)$ fractile of marginal probability distribution of b_i. The determination of B_i presents no problem, once the marginal probability distribution of b_i is known.

	Zone A			Zone B			Zone C			
	TP	R	MU	TP	R	MU	TP	R	MU	
(1)	1	1	1							≤ 6000
(2)				1	1	1				≤ 2000
(3)							1	1	1	≤ 4000
(4)	B_{11}	B_{21}	B_{31}	B_{12}	B_{22}	B_{32}	B_{13}	B_{23}	B_{33}	$\lesseqgtr BOD$
(5)	S_{11}	S_{21}	S_{31}	S_{12}	S_{22}	S_{32}	S_{13}	S_{23}	S_{33}	$\lesseqgtr SS$
(6)	V_{11}	V_{21}	V_{31}	V_{12}	V_{22}	V_{32}	V_{13}	V_{23}	V_{33}	$\leq V$
(7)	s_{11}	s_{21}	s_{31}	s_{12}	s_{22}	s_{32}	s_{13}	s_{23}	s_{33}	$\leq ST$
(8)	w_{11}	w_{21}	w_{31}	w_{12}	w_{22}	w_{32}	w_{13}	w_{23}	w_{33}	$\leq WT$
(9)	c_{11}	c_{21}	c_{31}	c_{12}	c_{22}	c_{32}	c_{13}	c_{23}	c_{33}	$\lesseqgtr C$
(10)	r_{11}	r_{21}	r_{31}	r_{12}	r_{22}	r_{32}	r_{13}	r_{23}	r_{33}	$\lesseqgtr R$

(1), (2), (3) - Area constraints (in suitable area units)

(4) - Water quality constraints (in suitable BOD units)

(5) - Water quality constraints (in suitable SS [suspended solids] units)

(6) - Permissible cuts (in suitable volume units)

(7) - Permissible visitor loads (in suitable units: ST-summer tourists)

(8) - Permissible visitor loads (in suitable units: WT-winter tourists)

(9) - Budget constraints (C in suitable money units)

(10) - Anticipated income (R in suitable money units)

Figure 3--The basic problem of management alternatives available for three forest zones: timber production (TP), recreation (R), and multiple use (MU)

BOD (bio-chemical ozygen demand)
= 120 units

$$B = \begin{array}{c|ccc|} & A & B & C \\ \hline TP & .005 & .006 & .005 \\ R & .01 & .013 & .011 \\ MU & .009 & .009 & .008 \\ \hline \end{array}$$

SS (suspended solids)
= 120 units

$$S = \begin{array}{c|ccc|} & A & B & C \\ \hline TP & .00 & .012 & .011 \\ R & .004 & .006 & .004 \\ MU & .013 & .014 & .013 \\ \hline \end{array}$$

V (volume of outturn)
= 2,400 units

$$V = \begin{array}{c|ccc|} & A & B & C \\ \hline TP & .21 & .23 & .20 \\ R & .012 & .03 & .015 \\ MU & .11 & .12 & .10 \\ \hline \end{array}$$

ST (summer tourist load)
= 2,400 units

$$s = \begin{array}{c|ccc|} & A & B & C \\ \hline TP & 0. & 0. & 0. \\ R & .20 & .10 & .15 \\ MU & .10 & .05 & .06 \\ \hline \end{array}$$

WT (winter tourist load)
= 10,000 units

$$w = \begin{array}{c|ccc|} & A & B & C \\ \hline TP & .5 & .6 & .4 \\ R & 1.3 & 1.4 & 1.1 \\ MU & 1.0 & 1.0 & .8 \\ \hline \end{array}$$

C (budget constraints - costs)
= 1,700 units

$$c = \begin{array}{c|ccc|} & A & B & C \\ \hline TP & .15 & .16 & .14 \\ R & .01 & .011 & .011 \\ MU & .05 & .06 & .04 \\ \hline \end{array}$$

R (income constraint)
= 3,600 units

$$r = \begin{array}{c|ccc|} & A & B & C \\ \hline TP & .3 & .41 & .25 \\ R & .0002 & .0002 & .0001 \\ MU & .17 & .22 & .14 \\ \hline \end{array}$$

Figure 4--Hypothetical data used for the problem in management alternatives.

Objective functions	Zone A: TP X_1, R X_2, MU X_3	Zone B: TP X_4, R X_5, MU X_6	Zone C: TP X_7, R X_8, MU X_9	d_1^-	d_2^-	d_3^-	d_4^-	d_5^-	d_6^-	d_7^-	d_8^-	d_9^-	d_{10}^-	d_4^+	d_5^+	d_9^+	d_{10}^+	RHS	Remarks
01				1	1	1	1	1	1	1	1	1	1	1	1	1	1	Minimize	
02				1	1	1	1	1	1	1	1	1	1	k	k	k	k	"	k = 9999999
03				1	1	1	1	1	1	1	1	1	1	k	k	k	1	"	k = 999999
04				1	1	1	1	1	1	1	1	1	1					"	
05				1	1	1	1	1	1	1000	9999	1	100	k	k	k	k	"	k = 999999 ad hoc weighted priorities
06				1	1	1	1	1	1	6001	k	1	100	k	k	1000	1	"	k = 21603600 weighted priorities calculated as per Priority Factor Algorithm (Field 1973)
Constraints																			
(1)				1														= 6000	
(2)					1													= 2000	
(3)						1												= 4000	
(4)							1							-1				= 120	
(5)	Elements as per Figure 3 and Figure 4							1							-1			= 120	
(6)									1									= 2400	
(7)										1								= 2400	
(8)											1							=10000	
(9)												1				-1		= 1700	
(10)													1				-1	= 3600	

Figure 5--Goal Programing Tableau for the problem in management alternatives.

t n ibe	Objective function used	No.	Variable description	Variable value (appropriate units)	Remarks
.	01	X_1	Area A - (TP)	6000	Min $(d^- + d^+)$, without weighted priorities
		X_4	Area B - (TP)	2000	Activities chosen (i) all A for timber production
		X_9	Area C - (MU)	2769	(ii) all B for timber production
		d_3^-	Unused area of C	1231	(iii) part C for multiple use
		d_4^-	BOD level <by	56	Satisfies water quality constraints with BOD less than upper limit.
		d_6^-	V level <by	403	Volume production falls short by 403 units and winter
		d_8^-	WT level <by	3584	tourist load falls short by 3584 units and income level
		d_9^-	C level <by	369	falls by 592 units. Budget is satisfactorily below
		d_{10}^-	R level <by	592	upper limit.
		d_5^+	SS level >by	0	
.	02	X_2	Area A - (R)	2333	Min $(d^- + d^+)$, with positive deviates given equal and very large weights x priority loads
		X_3	Area A - (MU)	3667	
		X_4	Area B - (TP)	2000	Activities chosen (i) part of A for recreation and rest for multiple use
		X_7	Area C - (TP)	3286	(ii) all of B for timber production
		X_8	Area C - (R)	714	(iii) part of C for timber production and rest for recreation
		d_4^-	BOD level <by	27	
		d_6^-	V level <by	841	Satisfies water quality constraints with BOD upper limit.
		d_7^-	ST level <by	1460	Volume production falls by 841 units, summer tourists
		d_9^-	C level <by	705	load falls by 1460 units and income falls by 1335 units.
		d_{10}^-	R level <by	1335	Budget is satisfactorily below upper limits.
.	03	Same solution as Solution 2. In this case minimization problem was same as 02, except that positive income deviate was not given large loading factor.			
.	04	X_3	Area A - (MU)	6000	Min (d^-) without weighted priorities
		X_4	Area B - (TP)	2000	Activities chosen (i) all A for multiple use
		X_7	Area C - (TP)	2286	(ii) all B for timber production
		X_8	Area C - (R)	1714	(iii) part of C for timber production and rest for recreation
		d_4^-	BOD level <by	24	
		d_6^-	V level <by	797	BOD level below upper limit but SS level is exceeded by 14 units.
		d_7^-	ST level <by	1543	Volume production falls by 797 units, summer tourist
		d_9^-	C level <by	741	load falls by 1543 units, income falls by 1188 units.
		d_{10}^-	R level <by	1188	Budget satisfactorily below upper limit.
		d_5^+	SS level >by	14	

6--Solutions of the model to the problem of management alternatives: timber production (TP), recreation (R), and multiple use (MU).

Solution number	Objective function used	No.	Variable description	Variable value (appropriate units)	Remarks
5.	05	X_2	Area A - (R)	6000	Min $(d^- + d^+)$ with specified weighted prioritie
		X_8	Area C - (R)	2000	Activities chosen (i) all A for recreation
		d_2^-	Unused B	2000	(ii) part of C for recreation
		d_3^-	Unused C	2000	Substantial part of forest left unused.
		d_4^-	BOD level <by	38	Water quality constraints satisfactorily below m Volume production and income fall down drastica y
		d_5^-	SS level <by	88	near zero level, summer tourist load falls by o y
		d_6^-	V level <by	2298	units and budget and income fall to nearly zero
		d_7^-	ST level <by	900	
		d_9^-	C level <by	1618	
		d_{10}^-	R level <by	3599	
6.	06	Same solution as 5. Same minimization problems as 05, except for weight x priority			

Figure 6 (Contd)--Solutions of the model to the problem of management alternatives: timber producti recreation (R), and multiple use (MU).

Figure 7--Solution for income maximization. All areas (A, B, and C) are chosen for timber production. Opportunity costs for non-basic variables and optimality ranges for RHS constraints and income coefficients are shown.

SUMMARY OF RESULTS

Variable number	Variable name	Basic Non-Basic	Activity level	Opportunity cost	Row no.
1	X1	B	6000.0000000	--	
2	X2	NB	--	.1634364	
3	X3	NB	--	.1981818	
4	X4	B	2000.0000000	--	
5	X5	NB	--	.2734364	
6	X6	NB	--	.2354545	
7	X7	B	3272.7272727	--	
8	X8	NB	--	.0908091	
9	X9	NB	--	.1554545	
10	--SLACK	NB	--	.0727273	(1)
11	--SLACK	NB	--	.1372727	(2)
12	--SLACK	B	727.2727273	--	(3)
13	--SLACK	B	61.6363636	--	(4)
14	--SLACK	NB	--	22.7272727	(5)
15	--SLACK	B	25.4545455	--	(6)
16	--SLACK	B	2400.0000000	--	(7)
17	--SLACK	B	4490.9090909	--	(8)
18	--SLACK	B	21.8181818	--	(9)

Maximum value of the objective function = 3438.181818

Figure 7 (Contd)--Solution for income maximization. All areas (A, B, and C) are chosen for timber production. Opportunity costs for non-basic variables and optimality ranges for RHS constraints and income coefficients are shown.

RNGRHS
******

(OPTIMALITY RANGE FOR RIGHT-HAND-SIDE CONSTANTS)
NON-SLACK RESOURCES ONLY

BI	XOUT	MIN BI Z-LOWER	ORIGINAL BI Z	MAX BI Z-UPPER	XOUT
1	12	5200.0 3380.0	6000.0 3438.2	6903.2 3503.9	15
2	12	1333.3 3346.7	2000.0 3438.2	4153.8 3733.8	15
5	7	84.000 2620.0	120.00 3438.2	121.40 3470.0	15

RNGOBJ
******

(OPTIMALITY RANGE FOR OBJ COEFFICIENTS)
BASIC VARIABLES ONLY

CJ	XIN	MIN CJ Z-LOWER	ORIGINAL CJ Z	MAX CJ Z-UPPER	XIN
1	10	.22727 3001.8	.30000 3438.2	*INF*	
4	11	.27273 3163.6	.41000 3438.2	*INF*	
7	9	.11846 3007.7	.25000 3438.2	.33000 3700.0	10

Variable number	Variable description	Variable value	Remarks
X_1	Area A - TP	1442	Activities chosen: parts of Area A get all management alternatives; ... B for timber production; Area C is partly chosen for timber productio[n] and partly for recreation.
X_2	Area A - R	411	
X_3	Area A - MU	4147	
X_4	Area B - TP	2000	
X_5	Area C - TP	1432	
X_6	Area C - R	2568	
d_7^-	V level by	851	All constraints bounds are satisfi[ed] as in Solution 02 (figure 6). Bud[get] level about same but income level improves.
d_8^-	ST level < by	1518	
d_9^-	C level < by	724	
d_{10}^-	R level by	1284	

Figure 8--Problem in figure 3 with elements in the BOD goal, chance-constrained. The solution of [th]e goal programing model of figure 5 using 03 for deviation loads is given below. (Compare solution 2 of figure 6.)

Since β_i provides a measure of the probability that any specific goal can be met or violated, a reliability measure for the system could be found by combining the component reliabilities, i. e.

$$\Pi_{i=1}^{m} \beta_i$$

We will illustrate the case when a_{ij} is a random variable by a simple example. Assume a_{ij} is normally distributed with mean $E(a_{ij})$ and variance $V(a_{ij})$. Consider the i^{th} chance constraint

$$\text{Prob}\left[\sum_{j=1}^{n} a_{ij} \cdot x_j \leqq b_i\right] \geqq 1 - \beta_i$$

Now

$$E\left(\sum_{j=1}^{n} a_{ij} \cdot x_j\right) = \sum_{j=1}^{n} E(a_{ij}) \cdot x_j$$

and

$$\text{Var}\left(\sum_{j=1}^{n} a_{ij} \cdot x_j\right) = \underset{\sim}{x}' \, \Omega \, \underset{\sim}{x}$$

where Ω is the variance-covariance matrix of a_{ij}. It follows that the constraint can now be written as

$$\sum_{j=1}^{n} E(a_{ij}) \cdot x_j + N_{\beta i} \cdot (\underset{\sim}{x}' \, \Omega \, \underset{\sim}{x})^{\frac{1}{2}} \ \ b_i$$

where the standard normal $N_{\beta i}$ is such that the cumulative distribution functio[n of] normal distribution,

$$\Phi(N_{\beta i}) = 1 - \beta_i$$

and

$$\text{Prob}\left[\sum_{j=1}^{n} a_{ij} \cdot x_j \leqq b_i\right] \geqq 1 - \beta_i$$

is realized iff

$$\left(b_i - \sum_{j=1}^{n} E(a_{ij}) \cdot x_j\right) \Big/ (\underset{\sim}{x}' \, \Omega \, \underset{\sim}{x})^{\frac{1}{2}} \geqq \ \beta i$$

The constraint is no longer linear. Ther[e a...] ways, however, under some relaxing assump[tio...] when the constraint can be made properly ... separable.

To study the effect of chance constraining, the BOD constraint elements (in proble[m] 03 of figure 5) on the optimal solution, w[e] adopted the above procedure. The a_{ij}'s of this constraint were assumed to be independently, normally distributed, so that the covariance terms in Ω were set to zero and β_i = .05. The solution only is presented [fo]r this study (fig. 8).

In some cases it may be appropriate to have r or more <u>joint chance-constraints</u> instead of ependent constraints. Such formulations can y be solved by techniques of nonlinear pro- ning. Nevertheless the approach of joint nce-constraints has some attractive features, deserves attention.

The implications of chance constraints are : tolerance measures, one for each con- int, or jointly for chosen goals, may be cribed by the decisionmaker with the implic- ost of such preassignment. Alternatively, rance measures may be optimally solved along other decision variables.

CONCLUSIONS

By its very structure, the goal programing od removes infeasibility and obviates the ssity for a single dimensional criterion in objective function. Goal programing, there- , deserves more attention in the management ning of resources for multiple goals--par- larly when no single measure can comprehen- ly evaluate all the facets of conventional rialistic as well as intangible values that lt from any management alternative.

Another form of programing--stochastic pro- ning--also merits wider application since : parameters in real life are probabilistic. ndard sensitivity analysis with LP can pro- only partial answers. The probabilities chieving specific goals can be incorporated hance-constrained programing formulations, some measure of system reliability can be ured.

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APPENDIX

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Investigations on Recreational Forested Areas

Ulrich Ammer

Abstract--In many European landscapes, two opposing processes are being practiced concurrently. In urban populated areas forest land is being cleared for development, and in agrarian areas far from any settlement, uncultivated land is often afforested.

While nearly all planners agree that the loss of woodlands near populated areas is undesirable, they often disapprove of making forested areas accessible through afforestation programs in agrarian problem areas because it may be harmful to landscape esthetics. The argument is advanced that increasing the amount of forested areas is done at the expense of landscape amenities. Until now, this judgment has originated from the subjective ideas of several planning professionals.

In order to present to forest managers and landscape planners ecological, economic, and esthetic decisionmaking aids, investigations were carried out with the support of the Deutsche Forschungsgemeinschaft of Baden-Würtemberg; the Ministry for Nutrition, Agricultural Economics, and the Environment; three provincial; and two municipal government organizations. The purpose of the study was to determine minimal, optimal, and maximum densities of representative forest land.

From these investigations, important planning directives would be derived which would...

1. Intensify the recreational and tourist function in rural areas, taking into consideration socio-ecological points of views, without causing damage to the attractiveness of the restive landscape, and

2. Achieve a balance between the quality of life and environmental protection on one side and permit the planning for the least amount of possible forested areas (even in populated sections) on the other.

STUDY AREA

The esthetics of any object is a matter of subjective phenomena, i.e., there exists no objective, agreed-upon-abstract, absolute method of judgment. Moreover, the esthetic value is always tied to associations of education, experience, and even psychic and physiological conditions resulting even in a measure of personal judgment. This measure of judgment can change

t lf independently of place, time, social in-
l nces, etc. It is therefore insufficient
o landscape-esthetic investigations to call
p the judgment of a series of "experts"--
o significant results can be obtained if it
s erived from groups of diverse users.

METHODOLOGY

Definitions

In contrast to the frequent previous in-
e igations in forestry's social aspects in
h h the area being studied is more or less
e ribed in verbal detail, we tried to present
o ur participants the object of a "forested
r " as quantitatively and as concretely as
o ible. In social science methodology,
k ches and pictures have proved eminently
u essful. Consequently, pictorial represen-
a on methods have been used successfully in
h conduct of numerous forestry-related social
c nce questionnaires, because they "concret-
z' the study object and lead the participant
o more exact expressions of opinion.

Among the various photographic techniques
h h are theoretically possible, (vertical,
o zontal, and oblique), we chose the oblique
e al photograph. In this manner, a photo-
r hic perspective was chosen with the part
f he forest nearest the study area with high
r uency of user contact given more weight
h those further away with lesser frequency
f ser contact. The pictorial excerpt is
h efore delineated so that the essential
d tification feature of the landscape can be
r ped. From these oblique photographs, ab-
t ct graphical sketches were prepared which
c ain all the identifiable features, such as,
e placement, hills and valleys, etc. All
e r factors which could influence the partic-
a 's response (such as color, shadow and
i t effects, clouds, etc.) can be kept con-
t t. These oblique photo sketches were
e loped into a corresponding montage of
v lays illustrating increasing afforestation
r 0 percent increments. The degrees of af-
e station were derived in this model with
e rd to economically significant parameters,
u as, site quality, relief, development,
n ownership patterns. The interrelated
r lems of photographic technique, choice of
i orial perspectives, and graphic represen-
a ion and other decisions are discussed by
a weg (1976).

Other investigators have demonstrated
at those being questioned can describe and
d tify adequately the actual forest condi-
i s. It was therefore assumed that the in-
e iewees rely upon real representation when
c ulating their responses to questions about
t experimentally represented forest areas.

The choice of participants in the questionnaire as well as their surroundings and their representativeness were chosen so that statistically reliable results could be developed.

The results of the questionnaire confirm first of all that respondents preferred that a landscape not exceed 80 percent forested area. This upper limit supports findings in an earlier study (Ammer and Lutz 1972) and is followed in forest management practices. Although a considerable portion of those being interviewed felt comfortable with an even higher upper limit, the majority felt that a landscape containing over 80 percent forested land was mirky and oppressive.

In terms of landscape esthetics, the lower limit of preferred forested area among those questioned was 20 percent. If a landscape had less than 20 percent forested area, it was considered "boring."

In contrast to these general results, noticeable differences resulted when respondents were asked about residential areas in populated sections. In this instance, the lower limit of 20 percent of forested areas was regarded as too low, and the preferred proportion of forested to residential areas was at least 30 percent. The upper limit was still 80 percent, even in this instance. A value of 60 percent was considered <u>optimal</u> for the populated section--this was statistically corroborated.

In rural areas, similar studies showed an optimal value of 50 percent forested land. This interesting difference in the conceptions between inhabitants of rural and urban regions might well be explained to a large degree by the higher degree of environmental quality and quietude in rural areas. This explanation is confirmed by the fact that in populated areas the amount of preferred forested areas--from the <u>viewpoint of recreation</u> and relaxation--was considered 68 percent and the upper limit was 90 percent. Interestingly, these attitudes correspond fairly closely to the wishes of resort guests (65-66 percent) in investigations of the tourist spots of Allgäus, the Black Forest, and the Swabian Alps.

The optimal figure for recreation areas was assumed to be 50 percent forested land in Kiemstedt (1967). When you realize that there exists 20 percent (in uplands up to a maximum of 40 percent) of actual forested land, the conflict of goals is apparent among agricultural, typical recreational, or optimal recreational area landscapes, although in the opinion of the participants, a rational land economy is still possible.

Table 1--Recommended lower and upper limits and optimal values of forest density for planning of landscape units, by area and function.

Area and function	Percent of forest to nonforest land		
	Lower limit	Optimal value	Upper limit
Populated areas:			
Residential	30	59	80
Nearby recreation site	40	68	90 - 100
Rural areas:			
Residential with industrial parks	20	45	80
Agricultural production	10	22	30 - 40
Nearby recreation	25	61	80
Vacation and resort activities	40	66	90 - 100

From the results, some interesting directions for planners are apparent in the recommendations for planning of landscape units (table 1). The recommendations include lower and upper limits and optimal values for forest density--the percent of forest to non-forest land.

UNTERSUCHUNGEN ZUM FREIZEITORIENTIERTEN WALDANTEIL

Zusammenfassung

In vielen europäischen Landschaften laufen 2 gegeneinander gerichtete Prozesse ab: in den städtischen Verdichtungsbereichen werden Waldflächen für Siedlung und Verkehr gerodet und in den agrarischen siedlungsfern gelegenen Räumen entstehen Brachflächen, die häufig aufgeforstet werden.

Während sich nahezu alle Planer darüber einig sind, daß die Waldverluste im siedlungsnahen Bereich sehr negativ sind, werden die Waldzugänge durch Aufforstung in den agrarischen Problemräumen nicht selten als landschaftsästhetisch unerwünscht abgelehnt. Es wird argumentiert, der zunehmende Waldanteil lasse landschaftliche Reize verlorengehen. Bei dieser Beurteilung ist man bisher weitgehend von subjektiven Vorstellungen einzelner Planungsfachleute ausgegangen.

Um für die forstliche Praxis ebenso wie für die Landschaftsplanung neben ökologischen und ökonomischen auch ästhetische Entscheidungshilfen anzubieten, wurden mit Unterstützung der Deutschen Forschungsgemeinschaft und des Ministeriums für Ernährung, Landwirtschaft und Umwelt Baden-Würtemberg in drei ländlichen und 2 städtischen Gemeinden Untersuchungen durchgeführt mit dem Ziel, Aussagen zur minimal, optimal und maximal vertretbaren Walddichte u machen.

Aus diesen Untersuchungen sollten planerisch wichtige Hinweise daraufhin erha er werden:

1. Wie unter sozio-ökologischen Gesichtspunkten die Waldfläche im ländlichen Raum id in Gebieten mit Erholungs- und Fremdenverke s funktion ansteigen kann, ohne daß Nachteile ü die Attraktivität als Erholungslandschaft e - stehen und

2. Welche Mindestwaldausstattung andererse s auch für Verdichtungsräume aus Gründen der Lebensqualität und der Umweltvorsorge gefor rt und erreicht werden müssen.

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1976 Inter-University Symposium on Renewable Resource Assessment and Programming: Executive Summary

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USDA FOREST SERVICE
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CONTENTS

Pemberton, Billy G.
1977. **1976 inter-university symposium on renewable resource assessment and programming: executive summary.** USDA Forest Serv. Gen. Tech. Rep. PSW- 21, 21p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The Forest and Rangeland Renewable Resources Planning Act of 1974 directs the Secretary of Agriculture to prepare an assessment of the nation's renewable resources and a program that will assure an adequate future supply of these resources. Responsibility for this work is assigned to the Forest Service. An inter-university symposium was held in 1976 to evaluate the first *Assessment* and *Program.* The workshop reports and the preparatory studies are summarized here, along with policy recommendations proposed.

Oxford: 903:U339.5
Retrieval Terms: resource management; natural resources conservation; Forest and Rangeland Renewable Resources Planning Act of 1974; public policy.

BILLY G. PEMBERTON was under contract to the Pacific Southwest Forest and Range Experiment Station as a technical writer to compile, condense, and synthesize the Symposium workshop reports and preparatory studies for publication.

In the Forest and Rangelands Renewable Resources Planning Act (RPA), which became law on August 17, 1974, Congress directed the Secretary of Agriculture to prepare an *assessment* of all the renewable resources in the nation and, for the resources on lands controlled by the Forest Service, U.S. Department of Agriculture, a *program* that would assure an adequate future supply of these resources while maintaining the integrity and quality of the environment.

The first assessment was to be ready by December 31, 1975, and is to be updated in 1979 and each tenth year thereafter. The first Program was also to be ready by December 31, 1975. It was to contain a four-year plan for 1976-1980 and a plan for each succeeding decade through 2020, subject to revision in 1980 and every 5 years thereafter. Each revised program is to cover at least the four successive decades.

The Secretary of Agriculture assigned these responsibilities to the Forest Service, which published drafts of the Assessment and the Program in August 1975 and the finished documents in December. The drafts were reviewed by interested public and private groups, including universities, industries, state and local governments, and other federal agencies.

In September 1975, the College of Natural Resources of the University of California, Berkeley, proposed that the Forest Service join it in sponsoring an undertaking titled "The 1976 Inter-University Symposium on Renewable Resource Assessment and Programming (ISRRAP)." The Forest Service agreed to this proposal and assigned responsibility to the Pacific Southwest Forest and Range Experiment Station at Berkeley, California.

The objectives of the Symposium were to encourage academic participation in constructive criticism of the first *Assessment* and *Program*, so as to provide the Forest Service with assistance in developing future assessments and programs. Certain qualified individuals at universities across the United States were invited to conduct preparatory studies on their campuses during the first 3 months of 1976. At the end of that time, each participant was to submit a report suitable for discussion at the three-day Symposium.

Studies were conducted at and reports were submitted from 10 universities.[1] The Symposium was convened at Pajaro Dunes, California, May 18-21, 1976, where five workshops discussed and reported on the *Assessment*, the *Program*, and the preparatory studies conducted earlier.[2]

This report summarizes the workshop reports and the preparatory studies.[3] Although it was not formally reviewed either by the ISRRAP organizing committee or by the Symposium participants before publication, it does provide a concise overview and synthesis of Symposium material. Specific policy recommendations in this summary were expressed in the workshops, but they do not reflect group judgment by Symposium participants.

The report is organized under three main headings: (a) Congress and the Law, (b) *Assessment* and *Program*, and (c) Information and Analytic Systems. The first chapter covers shortcomings

[1] Participating institutions are listed in Appendix A.

[2] Symposium participants are listed in Appendix B.

[3] This publication — a condensation and synthesis of Symposium workshop reports and preparatory studies — was prepared by Billy G. Pemberton, a technical writer, under contract to the Pacific Southwest Forest and Range Experiment Station.

and assets of RPA, suggestions for mending the shortcomings, and some reservations about the intent of Congress in enacting the law.

The second chapter covers general and specific criticism and commentary on nine main issues of the response by the Forest Service to RPA. The partitioning of the National Forest System (NFS) into six resource systems — the first of the nine issues — found no explicit support among the critics, although some perhaps lent tacit support by accepting the divisions without comment. Most of the participants, however, took occasion to comment, and most of them emphasized, to varying degrees, the need for an ecosystem perspective that makes classifying the parts secondary to defining the whole system.

The third and final chapter contains material that might more properly have been included as a subdivision of the second chapter. Because this first attempt to fulfill the requirements of RPA strongly suggests that the greatest single need is for more and better and more accessible data, information and analytic systems deserved to be discussed separately. Indeed, if the last system described is as good as it sounds, and if the money can be found to develop it, most of the problems associated with assessing and programming renewable resources would seem to be solved.

CONGRESS AND THE LAW

A broad and very general summary of the Resources Planning Act of 1974 is provided by the conclusions drawn by one team of critics who submitted the document to network analysis in a computer. RPA, as is true of most legislation, is a simple linear program with few articulate linkages. It functions implicitly, for essential bits of information and process are missing. Through implementation, however, the functional elements will become a more complex pattern of events, and linkages will inevitably become more articulate through experiment, usage, and precedent.

Though the conclusions drawn from such an analysis are themselves rather general, it will be seen that the specific conclusions drawn from non-electronic analyses support them remarkably well.

ASSETS OF RPA

The RPA has three obvious assets: (1) Establishing a five-year program will help relieve the problems that make managing natural resources on a year-to-year basis impossible. (2) Theoretically, there should be little fluctuation in the annual appropriation without a clearly substantiated change in the program on which the budget is based. (3) The Secretary of Agriculture's required annual reports evaluating the components of the program will improve the Forest Service's accountability and help Congress in its role as overseer.

That the Forest Service must include all 1.6 billion acres of the nation's forests and rangelands in its assessment implies other assets. The assessment could provide the data base for identifying the roles of other Federal land-managing agencies, for providing incentives for private industries and state agencies, and for identifying areas of needed research.

And finally, RPA is a step toward achieving an appropriate inventory of the nation's renewable resources, which, when accomplished, will permit better legislative and executive direction of Federal land-managing agencies.

SHORTCOMINGS OF RPA

The major flaw (some characterized it merely as an "interesting dilemma") of the RPA is vesting in one agency the responsibility for assessing all renewable resources in the United States, regardless of ownership. Program-planning requirements, limited to lands under the jurisdiction of the Forest Service, seem simple by comparison, and yet their fulfillment would have meant not only anticipating private resource supplies, but carefully articulating the plans between Federal agencies and between Federal and state agencies.

The *Assessment* and *Program* that were developed show that some cooperation occurred, but there is no evidence to indicate exactly how. Apparently, given the time constraints and the obviously deficient data, only *ad hoc* "coordination" was achieved.

To correct this problem, Congress should either give the Forest Service authority commensurate with its responsibility or reorganize appropriate Federal agencies into a Department of Natural Resources. In the second alternative, of course, authority would still be needed to ensure coordination between Federal and non-Federal agencies.

A concommitant flaw lies in Congress' failure to recognize that no methods exist for organizing the kind of data it calls for in the RPA. The Act should have specified such methods, and it should have specified the means of dealing with attendant problems. For example, the RPA requires the Forest Service to plan for meeting steadily increasing demands with steadily increasing supplies, but nowhere does it suggest the possibility of modifying demands.

A third flaw, exposed in a vigorous minority report, is the mountains of paperwork required to satisfy the demands of the RPA. Though such protests seldom have the desired effect, the reservations expressed below add force and cogency to this one.

In RPA, Congress had the opportunity to integrate the assessment and program of the nation's natural-resource subsystem with the full range of public objectives, yet there is much confusion and uncertainty about the intent of the Act. The inventory the Act calls for is time-consuming and expensive, which suggests a strong, committed intent, yet the 1975-76 budget suggests that Congress, in fact, intended very little. The Forest Service may thus be pressed into developing Assessments and Programs which are nothing more than promises "to be good guys and to try hard," legally bound to meet the operational requirements of RPA, but doomed by an inadequate budget to miss the chance to make truly important gains in the management of natural resources.

An obvious hazard is that the full range of landownership and sub-system problems may not be considered in developing the Program. When a demand is defined as exceeding probable supply, for example, the Program may develop a bias favoring a Forest Service activity and precluding a more efficient investment in private resources.

Such a risk could at least be reduced if Congress would confirm its ostensible intent with a budget proportional to its demands. Such confirmation would permit the Forest Service to develop and apply one or more of the analytical techniques described hereafter. Using such techniques — the reliability of which will depend on the specification of the model, which in turn will automatically define the inventory and assessment needs — will ensure that decisions have been based on obvious logic.

Schematic assessment and program interaction

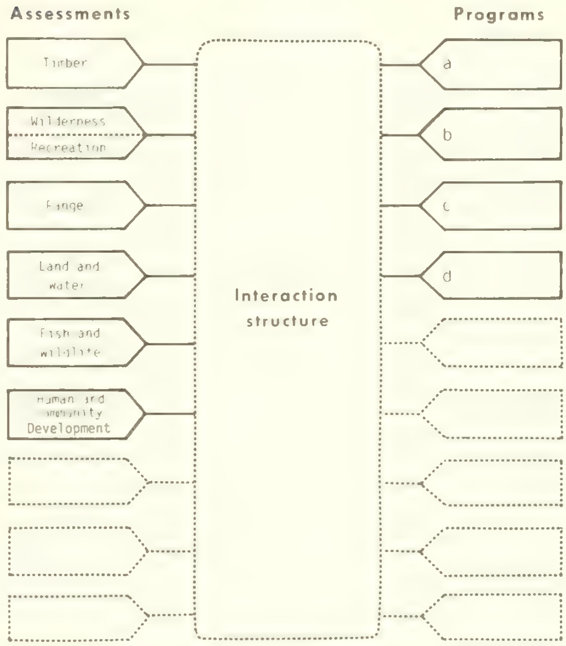

Figure 1—The required interactions of Assessment and Programs under the Forest and Rangeland Renewable Resources Planning Act (RPA) are suggested in this structure.

ASSESSMENT AND PROGRAM

The critics of the 1975 *Assessment* and *Program* universally agree that, given the time constraints, the Forest Service did a remarkable job. And almost universally they add, "Nevertheless, a better job should have been done."

The most significant weakness of the composite *Assessment* and *Program* is the absence of an explicit structure explaining the relations among the various assessments of demands and the various programs that resulted from those assessments. Although the Forest Service is best qualified to judge its own analytical capabilities, the following abstract structure suggests a common formal procedure for dealing with the required interactions (*fig. 1*).

Essentially, the structure should...

1. Be capable of functioning independent of geography, technology, and scale of activities;

2. Accommodate alternative networks consisting of interrelated operations based on (a) a general statement of goals, objectives, and methods; (b) a list of tasks with coordinating events ordered according to their nature; and (c) a test of the

structure for conformity to intuitive experience; and

3. Provide for development of interactive programs that permits continual reworking to deal with problems such as exceeding constraints.

The intent is to create a more rigorous planning process that increases accountability by allowing the agency to retrace planning decisions.

A general criticism of the *Program* is that the Forest Service fails to include a significant discussion of policies, laws, regulations, and such, that might significantly influence the use, ownership, and management of forest, range, and other associated lands. The Forest Service does describe the policy set that acts as a constraint on agency goals and activities, but it does not mention, for example, investment in submarginal timberlands, fee policies for various classes of resource users, or the effect of log-export controls on timber trade.[4]

SIX RESOURCE SYSTEMS

Most critics agree that the presentation of the six resources creates the impression that the National Forest System (NFS) is made up of discrete systems rather than of integrated, mutually-related parts. To obviate this impression and to maintain the integrity of the NFS, a better approach would be to show these "resource systems" as they really are: outputs of a single system, generated from a single collection of inputs (*fig. 2*).

Contributing to the apparent disintegration is the failure to show explicitly the reciprocal relations between and among the six systems. Obviously, a change in one affects all the others; although such mutual effects are without doubt difficult to assess, some attempt must be made. Substituting "resource *component*" or "resource *element*" for "resource *system*" would provide at least a partial answer.

A more profound failure of this partitioning of systems, and possibly also an effect, is that it stresses the sociopolitical part (economic, political, and technological relationships) of the biosocial system at the expense of the biological part (ecological relationships). The absence of ecological relationships should probably be attributed to the failure to view renewable resources as inherent and inseparable elements of a total ecosystem.

[4] A more comprehensive list is found in Appendix C.

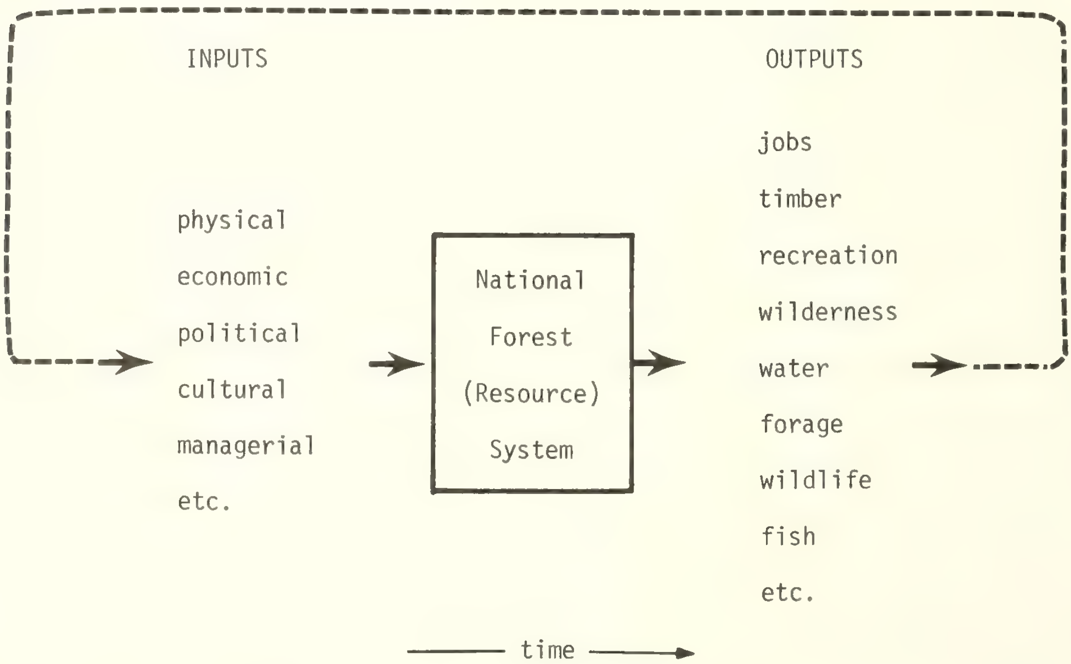

Figure 2–Resource systems of the National Forest System are actually outputs of a single system, generated from a single collection of inputs.

During the Symposium, detailed analyses were done by one or more critics on each of the six resource systems, except Human and Community Development, which as a new resource offered little for analysis. In the interests of economy and because these analyses reveal the same kinds of deficiencies, only the Timber analysis is summarized in detail. What is said about Timber can be taken as generally applicable to the other systems, again excepting the unique Human and Community Development resource, for which a summary of comments and recommendations is provided. The major distinction between the problems found in the treatments of the various resource systems lies in the Forest Service's attempt to assign economic values to essentially non-economic resources, such as Outdoor Recreation and Wilderness.

Timber

The timber resource drew a great deal of comment, none of it favorable. One critic found the supply curves unreasonable, the esthetic units unclear, the cost and supply data improbable, the supply-response projections unlikely, the criteria for allocating public funds spurious, and the environmental analyses disquieting. Turning to the major omissions of important objectives, this critic found that there was no discussion of the real alternatives in forest management, including accelerated harvest; no discussion of the necessarily different applications of the *Program* to at least some of the different regions and sites; and no discussion of uses for wood other than for structural materials and paper.

Assessments should be more localized, though quick, modestly detaiied studies of a few representative areas should provide approximations sufficient for actual application. And the *Assessment* should include the world requirements for and supplies of timber and timber substitutes in order to provide consideration of timber export as a program alternative.

Though the Forest Service is moving in the right direction with its attempt to provide demand schedules, its projection of timber demands assumes that product prices will remain constant at 1970 levels relative to alternative materials. This is a faulty assumption, for the cost of alternative materials, which are non-renewable and which require more and more expense for extraction and processing, will probably accelerate more rapidly than the cost of wood.

And finally, the data in the "supply" columns imply that production will defy nature by increasing as prices drop, decreasing as prices rise. This paradox leads to the conclusion that the data in fact represent *demand* estimates.

Range

Both the *Assessment* and *Program* suffer more from data deficiencies than from a procedural deficiency. Both are vague as to what range improvements should be implemented, where, at what cost, and with what result.

Wildlife and Fish Habitat

The data on wildlife and fish habitat are insufficient. Habitat requirements are not known for most species, and systematic estimates of population levels are made only for waterfowl and a few game species.

Land and Water

The Forest Service excluded the mineral deposits that underlie much of its land, on the grounds that those resources are not renewable. Nevertheless, provision should have been made for the possibility that decreasing energy supplies will lead to removal of these minerals by strip mining, a process that often leads to erosion and water pollution. Erosion and pollution are directly contrary to Forest Service commitments to improving soil productivity and water quality.

Outdoor Recreation and Wilderness

Although the *Program* anticipates continuing increases in population and per capita income by projecting a steadily increasing supply of recreational goods and services, it does not consider whether various alternative goals will induce desired effects for society. There appears to be no recognition that assumptions about population growth and user-fee assessment imply substantial subsidies to users of recreation services; and there is no accounting for the claim that the entire backlog of proposals will be completed by the year 2000 at a cost of 2.9 million dollars, while the single recreation project of the National Registry of Historic Places requires 9.4 million dollars for completion.

Human and Community Development

First, the Forest Service suggested that Human and Community Development was made up of discrete systems. Then the agency compounded the error by making it a separate and distinct resource system equal to the others. This conceals its relationship to the other "resource systems" and makes it subject to direct control, whereas it is really an output of the whole land system. The Forest Service ought to consider society not as something to manipulate and develop, but as something on which its manipulations of legitimate resources will have an effect. It should ask, for example, how its decisions and programs will affect the job market and the economy.

The business of the Forest Service is to manage the forests and rangelands and the related natural resources, where it has the knowledge to do a good job. The U.S. Department of Health, Education, and Welfare has agencies not only with the knowledge and skill to manage human and community development, but with legislative directives to do just that. If the Forest Service continues with its Human and Community Development as a resource system, it will inevitably duplicate the efforts of and come into conflict with better qualified agencies; and it will waste time and money that could be much better spent.

SOCIAL-IMPACT ASSESSMENT

Only three sections (3, 4, and 7-d) of RPA refer to social-impact assessment, and they do not directly answer the question of whether social-impact analysis is required for both the Program and the Assessment. Rationally, the answer is "no," because the scope of the Assessment is too broad (covering all the nation's renewable-resource lands) for such an analysis to have much meaning. The Forest Service, therefore, should assess only the social impact of the Program and only on a national scale. Whether analysis should be conducted at lower levels depends greatly on resolving problems relative to other sections of RPA (for example, the aggregation problem).

Four categories of intangibles lie outside the compass of economic analysis and yet are relevant to social-welfare accounts.

Opportunity Spectrum

Beyond the traditional economic elements are the concepts of *option value* and *existence value*, one of which may be applied to the social impact resulting from an irreversible decision or the implementation of a program. For example:

1. Range and diversity of goods and services provided: The widest range and diversity of goods and services yield the greatest number of consumption opportunities. Restricting this range causes a social impact.

2. Maintenance of options: Some management decisions or the implementation of some programs will characteristically preclude options. They may be termed irreversible and should be evaluated as future options foregone. The dimensions of the impact can be measured by its duration, distribution, and scope.

3. Non-substitutable and irreplaceable goods: Another type of option maintenance is the management decision that irreversibly reduces the supply of resources and intermediate goods for which there are no substitutes (amenity resources, for example). The social impact is measured by the degree to which this supply is reduced and the future options foregone.

4. Existence value: Not all social benefits from renewable resources derive from direct use or contact. Some vicarious benefits come simply from knowing that a resource exists. Management decisions on such a resource cause an impact on these existence values.

The Forest Service should identify the widest range of possibilities for social impact that might result from program activities. This range of possibilities should then be weighed against the other criteria used in determining the alternative program goals. The agency should in fact develop a master list of such possibilities for use by both program planners and field personnel, for use at every level.

Distributional Effects on Clients

This category deals with the influence of program outputs on identifiable social groups. The two questions to ask are: (1) Who benefits and who pays? (2) What are the sociocultural changes?

The first question can be answered in terms of the *scope* (numbers of people and things affected), *intensity* (degree to which future options are foregone), and *duration* (length of time of impact) of effects on social groups. A partial list of variables describing these abstractions includes type of occupation, education, income, age, sex.

Sociocultural changes include the effects of a program on social structure, subcultures, and population. Effects on social structure are comprised of changes in social stratification and kinship ties. Subcultural effects concern tradition, customs, language, and lifestyle. Effects on population have to do with demographic data such as migration, mobility, and age/sex ratios.

National Materials and Energy Accounting

The products (*e.g.*, wood) from Forest Service programs greatly influence the use of materials and energy (*e.g.*, petroleum and coal) in the United States. Thus, changes in the agency's wood-production programs and in materials and energy policies not only affect each other, but also have profound effects on society. Wood is related to materials and energy policies in several ways. Wood may be used as fuel, a renewable substitute for fossil-fuel energy reserves. Wood may be used in construction in place of asphalt or steel or aluminum, which requires comparison of the effects of alternative programs on non-renewable resources. New programs may call for conserving capital stocks and re-using wood products. Timber stocks may be maintained as a reserve against future national emergencies.

International Trade Policy

The United States trades on the international market. We import and export timber and fiber, and we import great quantities of petroleum. Changes in world-wide potential and need for resources can affect us and our natural resources greatly.

An International Trade Policy account is therefore necessary, for economic measures such as National Income do not adequately reflect the environmental and social consequences of foreign trade.

New Approach

A different approach to assessing social impact has the added feature of involving the public much more directly in decision-making. Traditional methods of assessing social impact leave much to be desired. In seeking to quantify essentially qualitative things — feelings, wishes, opinions — the analysts may project their own value judgments. Furthermore, too often the assessor relies on economic and demographic data or on sampling techniques that emphasize randomness and representativeness; in either event he probably fails to get what he was searching for — the deeply felt community and individual needs, desires, and direction.

The Foundation for Urban and Neighborhood Development (FUND),[5] a Denver consulting firm, has developed a technique that differs two ways from traditional methods: (1) FUND separates the social and cultural elements from the economic, because the economic elements do not contribute information relative to the qualitative problems; (2) FUND has developed a process, as opposed to an assessment, which both diagnoses and seeks to involve all relevant parties in strategies for coping with or avoiding the negative effects of a proposed project. This nonsequential, interactive method is intended to be a learning experience for all participants: private citizens, agency personnel, industrial representatives.

To determine the dimensions of social impact, FUND consultants enter a community as "strangers," engaging people in what they term the "discovery process": they have people describe (1) individual and cultural lifestyles and values and how they are exercised in informal social networks; (2) the movement and interaction of people within the natural environment; (3) individual perceptions of and relationships to social institutions and systems; (4) how individuals and groups perceive work, get training for jobs, and relate as employees and employers.

The object is to identify the mechanisms by which an individual will adapt to and absorb changes that will result from a proposed project, so that specific recommendations may be developed. Each impact requires criteria for measuring performance in mitigating the impact and a time-table for its resolution.

FUND's approach proposes that the community rather than the bureaucracy should find the solutions. Caution should be exercised, however, in assuming that the individual should "adapt to and absorb" the changes. In some instances, resistance to a project might be more appropriate, and efforts to help find means of coping would likely cause resentment and conflict. An alternative, probably superior, would be to make the

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[5] Trade names and commercial products or enterprises are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

plans adaptable to community needs, in which case the social and cultural information collected and evaluated should be made available to the affected people.

PUBLIC INVOLVEMENT

Most environmental policy acts provide for some citizen participation in forming policies. In recent years this participation has increased, with individuals or groups sometimes asking the courts to require performance by the agency.

There are many ways of getting the public involved, all of which the Forest Service is familiar with. But the most effective methods — workshops that permit education and close exchange of viewpoints — reach a primarily local audience. An effective means of reaching a wider range of respondents is needed, two of which are herewith suggested.

Charette Workshop

For about 4 months, the Forest Service conducted numerous meetings with groups, individuals, and organizations, soliciting support and public participation. During the last 5 weeks, information was broadcast through the news media, who were invited to cover the Charette meeting scheduled as an around-the-clock workshop to be held on a weekend at the Sam Houston National Forest in Texas.

At the meeting, participants were given packets of data and assigned to teams. Special "consultants" visited the teams to provide additional information as required. On Sunday afternoon, all the teams submitted their alternative proposals. During the next 9 days, Forest Service personnel evaluated these alternatives, rejecting the few that were unworkable, rewriting others for clarification. All the retained proposals became an integral part of a final *Environmental Statement and Unit Plan*.

Codinvolve System

A Forest Service research team developed this "applied content analysis system" when other systems proved unsatisfactory. It is grounded upon a set of principles and criteria that will provide an accurate, understandable summary of public response. The system can be adapted to any field level (using edge-punch, card-sorting techniques where computer assistance is not available) — and is designed for easy computer operation.

Analysis of public input provides the decision-maker with a display and summary of the opinions for, against, or about the issues in question, and the reasons behind them define the values of the different segments of the public. To make the Codinvolve system function as envisioned, the Forest Service researchers formulated a list of 10 specific criteria for analyzing public input. The method should

1. Summarize the extent, content, and nature of public input in relation to the decision-makers' questions;
2. Be objective;
3. Be visible and traceable;
4. Be reliable, in that the opinions expressed are recorded the same way by different analysts;
5. Provide for uniform application among different administrative units;
6. Be flexible, to accommodate different conditions;
7. Have the capacity to handle large quantities of input, to store and retrieve input, and to assimilate continuing input;
8. Summarize the balance of opinions expressed and describe variations in each opinion;
9. Provide other descriptive and qualitative information about the content and nature of input; and
10. Facilitate environmental analysis leading to preparation of final environmental impact statements by identifying all significant information and arguments for and against the proposed actions.

Since Codinvolve was developed in 1972, it has been used in a number of studies to analyze thousands of inputs from the public. The system has proved to be an excellent tool for providing the land manager (*i.e.*, decision-maker) with objective, undiluted data in a manageable form when the above principles and criteria guide the conduct of the analysis.

ECONOMIC ISSUES AND METHODS

The *Assessment* and *Program* stimulated many comments about economic issues, some of which have been mentioned elsewhere. Some critics complain that the entire effort is based on economic concerns and values. Others find that the Forest Service had inadequate data, or that it

misused the data, or that appropriate methods do not exist. The following examples, chosen almost at random, barely suggest the range and diversity of the commentary on this subject.

Supply-Assessment Methodology

To serve as the basis for a program, an assessment must provide capital-budget schedules showing feasible production- and cost-alternatives for each resource-system output. These data can then be combined in various mixes to determine the most economical combination for the program, and when a program is chosen, the required budget is known. If place-specific, locally-feasible alternatives were collected at the national level, the program could be allocated back down to the site of origin with reasonable certainty that the budgets would earn the desired responses.

To generate an investment schedule (capital-budget schedule), the assessment must...

1. Identify specific areas;
2. Determine what is being currently produced;
3. Estimate what could be produced under different feasible treatments;
4. Estimate the costs of those treatments; and
5. Rank the prospective increments in supply by the cost per unit of providing it.

Underlying this supply framework is the basic production function for a particular output. For most of the resource outputs, land is the basic factor of production. The amount of output is the quantity of land allocated to producing that output multiplied by the average productivity per unit of area. Output (or yield) is the growth or annual carrying capacity, whether used (consumed) or not:

1. *Current-Production Assessment* — To find a given yield from a specified area, it is necessary to know (a) the number of acres and its productivity class and management intensity; and (b) the average annual production per acre on land in that productivity class and with that management intensity. Multiply these two factors to get an estimate of the current yield.

2. *Stock Assessment* — The land already carries, in some areas, a stock (standing crop) of timber, fish, and wildlife. The current yield of one of these resources is related not only to the productivity of the land, but to the amount and composition of the standing crop, which therefore must be assessed. The method is the same as for finding current production, but the second factor changes: (a) The number of acres and its productivity class and management intensity; (b) average standing crop per acre on land in that productivity class and with that management intensity. Again, multiplying these two factors provides the desired estimate.

3. *Potential-Production Assessment* — A similar but more complex method permits assessment of the possibilities for changing production. In brief, production may be changed in two ways: (a) by changing the number of acres devoted to that output; (b) by changing the management treatment. Of these two, the second is far more complicated to calculate. The problem with the first is a matter of identifying specific areas in order to simplify budgeting allocations.

Assessment Methodology

There is no market mechanism for establishing the necessary demand functions for such services as wildlife and recreation. The RPA analysts either improvised *ad hoc* procedures that provided illogical relationships (timber), or estimated likely consumption at zero price (recreation). The RPA programmers merely expressed demand (for wildlife and recreation) as an arbitrarily fixed price, regardless of the level of consumption.

A better method would be to fashion synthetic demand relationships from case-study information that indicates that the demand for recreation and wildlife activities is income- and price-elastic (an increase in income causes an increase in demand; an increase in price causes a decrease in demand). These "synthetic" relationships would have to be developed by expert judgment, which means that they would still be only estimates. Nevertheless, they would be better than no estimates at all, and they would have the virtue of being internally consistent.

Production Function

A better model (than the Forest Service used) would allow better use of the data (than the Forest Service managed), which is inadequate and will probably remain so unless new research is implemented. This model, like the improved assessment methodology, above, would require a panel of experts to render judgment on case data. Here, the object is to synthesize production functions (a mathematical relationship that shows how

various inputs are related to changes of output). The test will be whether they contain plausible relationships and appear consistent with general empiric information.

Cost-Effectiveness

Tests of the internal cost-effectiveness of pairs of goals within each resource system show such wide differences in marginal benefit-cost ratios as to suggest that the proposed program represents a socially optimal program. There is also the uneasy feeling that the programs, including the recommended one, are arbitrary and completely judgmental.

The programmers need, among other things, to standardize the bases on which their cost-benefit analyses are made. For example, benefits to Timber include consumer surplus, while benefits to Wildlife and Recreation assume that the intrinsic social value is equal to an arbitrarily established price that remains the same no matter what goal is selected.

Supply and Demand

The Forest Service should consider the National Forests as economic entities in which supply and demand are regulated by anticipatory pricing, thereby relieving the pressure on policies which rely heavily on projections of basic variables. It should also make clear the assumptions underlying projections, so that all the decision makers may be aware of the associated limitations.

AGGREGATION AND DISAGGREGATION

This subject, too, attracted much commentary. Of all the suggested models, the following is the most complex. It is offered as representative because it provides the greatest detail, and because it has the features emphasized in all the models: that local managers participate in assessment and planning, that aggregation progress from the lowest possible level to the national level, and that disaggregation proceed from the national to the lowest possible level.

The assessment and program are separate but interacting activities, each with its unique locational, data, and timing requirements; and each requiring a methodology that permits disaggregation from the national to at least the regional level, and aggregation from the local to the national level.

Three basic questions are relevant to an assessment and programming that begins with a relatively small geographic unit and aggregates information vertically to higher levels:

1. How should assessments be displayed and aggregated?
2. How should assessment data be used to guide program design:
3. How should programs be designed and aggregated?

The answers to these questions imply and are based on precepts embodied in the following process.

Stage 1: Assessment

The Assessment should begin at the local aggregation unit and be specific to an ownership class (*e.g.,* National Forest, industrial forest). Initially, each planning-unit staff should develop a marginal cost-supply relationship (a "what-if" model, not necessarily a market-supply curve) for each type of good or service to be produced. These would be forwarded to the regional level.

At the regional level, supply relationships would be aggregated and combined with a regional demand model to derive a tentative set of output targets for the region and perhaps for each sub-unit, keeping in mind the regional- and national-welfare interests. This process would also yield a set of relative prices for the various outputs as well as a first approximation to the portion of the total output to be supplied from the National Forest land, thus completing the first stage of an interactive process.

Stage 2: Program

In the second stage, analysis centers on program design. Each local planning-unit staff would develop programs for a series of alternative budget levels administratively specified at the regional level. These alternative budgets would represent incremental additions to or subtractions from a current base-level budget. Each program would be described as program inputs and an *output mix. Relative prices* from the regional assessment analysis would guide decisions regarding this mix, although they would not be binding, and thus could be adjusted to reject a local situation. In fact, these relative prices may be negotiated in the planning process; that is, the final set may most likely appear as the result of the iterated process.

Local alternative programs would be aggregated at the regional level, thus yielding a regional output mix for each alternative budget. A set of relative prices would emerge at this point, to be checked against the assessment stage set for consistency. After making adjustments to achieve internal balance, programs would go forward to the next higher administrative level.

A number of conclusions should be pointed out:

1. Neither the aggregation framework nor the process model are practical for total adoption by 1980, but they do provide a recommended framework for assessment and programming for the period beyond.
2. To some, it may seem that the assessment model recommended here places undue emphasis on economic efficiency and prices at the lower geographical and administrative levels. This state of affairs is unavoidable. Any program-design work as mandated by the RPA will require this level of emphasis on economics, and it is better to have this element explicit rather than implicit, as was the case in the 1975 effort.
3. The recommended process presumes that the cycle of assessment precedes the cycle of programming with sufficient lead time, probably 2 to 3 years.
4. Future assessment, program-development, and implementation efforts will require personnel with substantial skill in data analysis and model development at the lowest and middle levels.
5. Guidelines regarding standards for data analysis and program design must be developed for uniform application at every level.
6. The conceptual recommendation stated herein for the dual efforts of assessment and programing in part extend beyond the state of the arts and in most cases lack systematic empirical verification. These existing constraints, however, underscore the need for a continuing research program to parallel and support the adoption of these recommendations for future RPA assessment and programming.

INTERAGENCY COORDINATION

The Forest Service has to have the cooperation of various entities outside its own agency, yet it has no power to command that cooperation. It therefore must invite others (*e.g.*, U.S. Department of Interior) to participate on its planning committees. It can establish advisory committees at the various levels and invite outside participation appropriate to each level, and it must work out cooperative agreements with the other Federal agencies responsible for forest and range lands. The object of these efforts is to secure needed data and improved programming techniques, and to help create a consolidated information system.

Similar cooperative ventures should be established with state forestry divisions, university forestry departments, and forest industries. Persuasion and tact might gain voluntary cooperation, but grants for seminars and research should be considered if funds are available; and private industries might be prompted by offering them technical assistance, forest protection, and other inducements.

States with considerable areas of state forests should be encouraged to formulate complementary RPA programs of their own, especially in their land-use planning. Critics of the Jackson and Udall national land-use planning bills have unjustly but effectively aroused much public antagonism to such bills on the grounds that they represent Federal intervention. The present approach should circumvent that antagonism by sharing the data it gathers with the National Resources Council, which in turn uses it to project resource policies of value to the various state and local planning agencies.

Essentially, this approach avoids the planning-from-above that many critics fear. It offers, instead, a method by which local planning provides the basic data for national resource assessments and a national means of dealing realistically with local problems.

FOREST SERVICE REORGANIZATION

In order to meet the requirements of the National Environmental Policy Act and RPA, the Forest Service must undertake integrated interdisciplinary planning and incorporate extra-market values and meaningful public participation. Hiring a few non-foresters for staff positions is not an adequate organizational response, because forestry professionals continue to dominate the top policy-making positions.

Instead, the Forest Service must completely refurbish its organization. The planning process should be aligned with the budgeting process in order to increase coordination and reduce conflict over goals, jurisdiction, financing, and accounta-

bility. Policies that need articulating are criteria for evaluating social and cultural effects at each level; a decision-making process for the gathering of data, the development of alternatives, and the participation of the public; and a methodology for coordination, both laterally and vertically.

To achieve these ends, multi-disciplinary (social science) personnel must be made available at all levels, because regular USFS personnel have not the appropriate conceptual and analytical skills. These professional social scientists, using a variation of the FUND process (described above) whereby they are the "strangers" and the Forest Service is the "community," will train other personnel in social-impact-assessment methods, in group-process skills (including conflict management), and in dealing with social and cultural problems in routine work.

A more complex organizational change is necessitated by the intrusion of the non-foresters, whose presence and work have differentiated the organization, have made it less capable of coordination, both internally and externally. Internally, better communications, education, and training will of themselves help to effect coordination, especially if planning teams include representatives from other levels. Externally, consultants can mediate among the diverse elements trying to make planning and program decisions. Flexibility at the local level may work to direct meaningful social change and preclude conflict. If they can be made credible to the public, staff members might themselves be taught to mediate.

ECOSYSTEM PLANNING

Ecosystem may be defined as "the interactions of the living and non-living parts of the environment." Within the environment, an ecosystem functions by maintaining a flow of energy and a cycling of materials. The materials cycle continuously between the living and non-living elements. The flow of energy, on the other hand, is non-circular, comes mostly from the sun (some comes from fossil fuel and nuclear processes), and ultimately dissipates as heat.

Because ecosystems are the basic production systems for a society, and because the national economy is a system for processing matter and energy to serve human needs as efficiently as possible, it makes some sense to develop budgeting systems in which the units of measurement are quantities of energy and materials. Decisions about the mix of inputs and outputs in a given ecosystem may be described according to how they modify the flow of energy and the cycling of materials. These decisions can then be evaluated by economic or other social values.

The renewability of a resource really depends on the magnitude of the energy flux (the quantity of energy) and the time required for renewal. Renewability can thus be expressed only in terms of the rate of resource formation with respect to human values, technology, and planning horizons. In other words, any resource is theoretically renewable. Once we determine, by analysis, how much energy is required over how long a time, then we can, by evaluation, determine whether we want to make that expenditure of energy and time.

The Forest Service's product-oriented approach to planning has three basic flaws:

1. It is too simplistic; it underestimates the multiplicity of values, goods, and services provided by forest and range lands (the *Assessment* and *Program* failed to mention at least 60 specific renewable resources);

2. Its static classification of natural resources assumes that the current definition of natural resources will obtain in the future; and

3. It provides no framework for analyzing the social and ecological interactions among the resource systems.

Future assessments ought to examine the fundamental ecosystem processes involving the flow of energy and the cycling of materials in order to provide a more comprehensive basis for long-range planning. If it has not already become so, the traditional multiple-use approach will soon become obsolete, when the multiplicity of new demands becomes apparent.

A second report applies energy-accounting methods to California chaparral in order to demonstrate how accounting for all the energy in plants and fuel reserves provides the needed scientific basis for a socio-environmental methodology that avoids politics by separating analysis from evaluation.

INFORMATION AND ANALYTIC SYSTEMS

Demands for renewable resources have increased more rapidly than have the manpower and budget required to meet those demands. Now, RPA mandates even broader responsibilities for the Forest Service, which means that new systems techniques — some already developed and proven — must be pressed into ser-

vice: inventory and overlay systems for classification and assessment, resource-allocation models and benefit-cost analysis for the program, simulation models for analysis of basic inventory data, and the rigorous land-classification model that does everything but chop the trees.

INVENTORY

One of the RPA requirements is for the assessment to contain an inventory of present and potential renewable resources, which implies a classification system. In such a system, a manager needs to have a clear understanding of his purpose in order to determine what types of data are required: What resources and how much detail? Generally, the greater the detail, the better.

Traditionally, the Forest Service has inventoried resources by the slow and costly "single factor" surveys (*e.g.*, topograpic, geologic, vegetative) rather than by a faster and less costly method such as physiographic terrain analysis, which uses air photo and other remote-sensing methods. If the Forest Service continues to use this method, an overlay-mapping system is essential for determining the relationships between resources in order to get at the potential supply. Designing the resource inventory around an automated geographical data-base, for example, would permit computer testing of interactions between resources and would yield an informative report on potential production.

OVERLAY MAPPING

Two overlay-mapping systems for representing resource information in a computer, *grid cell* and *polygon*, have seen limited use within the Forest Service.

In the grid-cell system, a base map is overlaid by a cellular map, each cell of which is then coded according to a predetermined classification scheme. Though a cell may feasibly represent any area, the smaller the size of the cell, the greater the detail. Many different grid-cell programs are available, all easily but tediously coded for computer manipulation and all useful tools for examining the characteristics of geographical areas. The map may not conform to what the manager is accustomed to reading, but it can be made easier to read by coloring or shading or by contrasting coding symbols.

The polygon system was designed to make up for deficiencies in the grid-cell system. It is more realistic and more esthetic; it avoids the tedious coding each grid cell requires; and most importantly, it permits aggregation of data. As with the grid-cell system, many different polygon programs are available. Although the polygon system is technically more complex than the grid cell, it gives ultimately superior results.

ALLOCATION MODELS

Resource-allocation models range from simple linear to complex non-linear. Many have been developed by or for the Forest Service. These models — which consist of mathematical routines that, given a decision criterion or criteria, match resource capabilities and potential with use demand — are well adapted to the agency's needs. Four representative models are described next.

Timber RAM (Resource Allocation Method)

The Timber RAM uses linear programming to achieve any one of five possible objectives: maximize gross revenue 1, maximize gross revenue 2, maximize net revenue, maximize the volume harvested, or minimize cost. The resource area should be stratified into timber classes, the alternative silviculture treatments designated, and the objective defined. Each silvicultural alternative requires information on growth, net revenue, volume, and costs. In addition, constraints on accessibility, harvest needs, allowable cut, and budget availability may be entered. Although it is limited to considering a single resource and a single objective, it has great potential for use in local planning for scheduling timber harvests over a long period of time, which it does efficiently and economically.

Resource Capability System

Based on linear-programming concepts, the Resource Capability model is used for multiresource planning, and includes a procedural-planning framework and a systems-analysis approach to forest and local planning. It schedules multi-resource strategies over time, allocates acreage to specific management activities, and identifies levels of output for each product in response to this allocation. Parametric analysis permits the user to see the effects of changes. Already in use in several regions, this system has future possibilities at both the forest and local levels.

Goal Programming

This multiple linear program allows multiple objectives in different units of measure. It attempts to meet the needs of the goal with the highest priority before considering others. As it considers progressively lower goals, it does so without detracting from the higher goals. The program has been used at the regional, forest, and unit levels and *can* be used at any level. It can be used at all levels of RPA assessment and programming, and can serve to improve communication between levels. If the alternative programs set forth by the Forest Service were assigned priorities, this system would provide ideal analysis.

Economic Harvest Optimization (ECHO)

This dynamic program model incorporates a binary-search technique. ECHO joins a biological-yield model with an economic model and charts the optimal rate of timber harvest in a condition of excess inventory. Although it is economically efficient, used by the Forest Service it would doubtless lead to a mis-allocation of resources, because it can reveal only the most profitable course, which is not always the best.

BENEFIT-COST ANALYSIS

A project is economically feasible when the benefits accruing with the project are equal to or greater than the cost of the project plus the benefits that would accrue without the project. Although neither the tangible benefits and costs nor their monetary value can always be easily determined, such a procedure forces the decision-maker to consider objectively the merits of a proposed project. Thus it is valuable even when economic efficiency is not the main criterion.

SIMULATION MODELS

Simulation models identify the important characteristics of a system and lead to a better understanding of its components and of the relations between components. Until the last 2 or 3 years, these models were limited by being site- and problem-specific. Recently, however, the models have become more generalized and thus more practical, although they have dealt primarily with only two resources (timber and water) in a multiple-resource system. Following is a timber model which will, at some future time, accommodate other resources and products.

Economic efficiency is, as specified in RPA, important to any planning process. Equally true, society should get any given level of timber production at the least cost in resources.

This framework will directly address the call for more disaggregation in Assessment and Program analysis because one of its economic dimensions is space. It will also address obliquely the need to consider explicitly the interactions between the multiple products of the forest and rangelands. Once this framework is drawn, other resources and products can enter the analysis either in complement to or in competition with the timber system.

Of the many characteristics relative to timber production, only three — space, form, and time — will figure here as dimensions of the timber economy. Others are land quality and operability — functions of soil, climate, and topography — which determine not only the biological potential of land to grow wood but also the total resource cost of managing and harvesting the wood grown. Still others are ownership, tract size, timber size and type, accumulated inventory of timber, and alternative land uses.

An even more important characteristic, but one that is often ignored in planning, is nearness to market. Transportation can amount to as much as a third or more of the selling price. Because it is more efficient to haul processed lumber than roundwood, the manufacturing plants usually locate as near the timber source as possible.

All of these characteristics vary over space. The variation is small *within* a homogeneous timber region, but large *between* timber regions. In national planning, therefore, it is necessary to aggregate the commercial forest lands into a system of geographic timber — supply regions, each of which is homogeneous as to the spatial characteristics that determine the efficiency of growing, harvesting, and processing timber.

Transportation costs provide the economic link between those regions and the regions of another set that center on major urban areas and describe geographic wood-consumption patterns. Each region of each set has an economic center-of-gravity, which means that all possible trading routes and all transportation costs can be calculated for items that move inter-regionally.

Some timber regions are nearer their market than others are, so that transportation costs are

lower. Others may have lower harvesting or processing costs. In the long run, the supply regions with the lowest costs for delivered products will have the highest stumpage value, which value is a direct measure of the efficiency with which each region supplies society with timber products.

As an economic dimension, *form* refers to the alternative products that a resource or raw material can produce. From timber comes, for example, pulp, lumber, plywood. The precise use to which it will be put depends partly, of course, on what will allow the buyer the greatest profit, but it also depends to a high degree on timber size and species. Thus, the species and size distribution of the timber within a supply region has great analytical significance.

The lack of an adequate processing plant could for a short time prevent the best allocation in the form dimension, but entrepreneurs would quickly correct such a deficiency by relocation or expansion.

Forest growth and renewal occur only over a long period of time, but harvesting and processing, spurred by consumer demand, build up rapidly to deplete the timber faster than it grows. Necessarily, the most intense production will develop in the best locations; and as the inventory begins to fail, mills will be abandoned for lack of timber or relocated on better sites.

Program planners must consider the economics of long-range regional advantage in the wood industry, for the industry will likely refuse to go where there is not maximum cost-effectiveness.

The Model-Timber is the basic unit of analysis: (a) the national market for wood products is divided into 23 demand regions; (b) consumption is divided among 11 primary wood products, and requirements over time are specified in the demand regions; (c) aggregate commercial forest land and timber resources are broken down into 17 supply regions; (d) timber is cross-referenced by owner and species/size distribution.

A linear programming (LP) model — representing the company that cuts, processes, and transports the wood — describes the production possibilities and costs of translating each supply region's timber into delivered products. Processing capacity and timber availability constrain production. Timber is allocated, on the basis of efficiency (minimum total cost), through processing plants within the supply regions and out to consumption regions to satisfy demand requirements. For each successive time period, the timber is grown, then cut to meet consumer requirements.

The details presented here are representative, not complete. The point is that organizing the vast array of data for the timber system alone demands the use of such an interdependent framework. And once the framework exists, more variations are possible. Adding new constraints, activities, and coefficients should offer an even broader range of strategies and programs; and modifications would permit interactions with other systems. The capacity of this kind of framework is the capacity of the computer.

This framework represents planning from the top, for in the future, definite national production-levels must no doubt be established as policy in order to meet basic living standards. The logic of a framework will, when regional allocations are communicated to the local level (as they must be), help ensure that local planners maintain their priorities under local pressure.

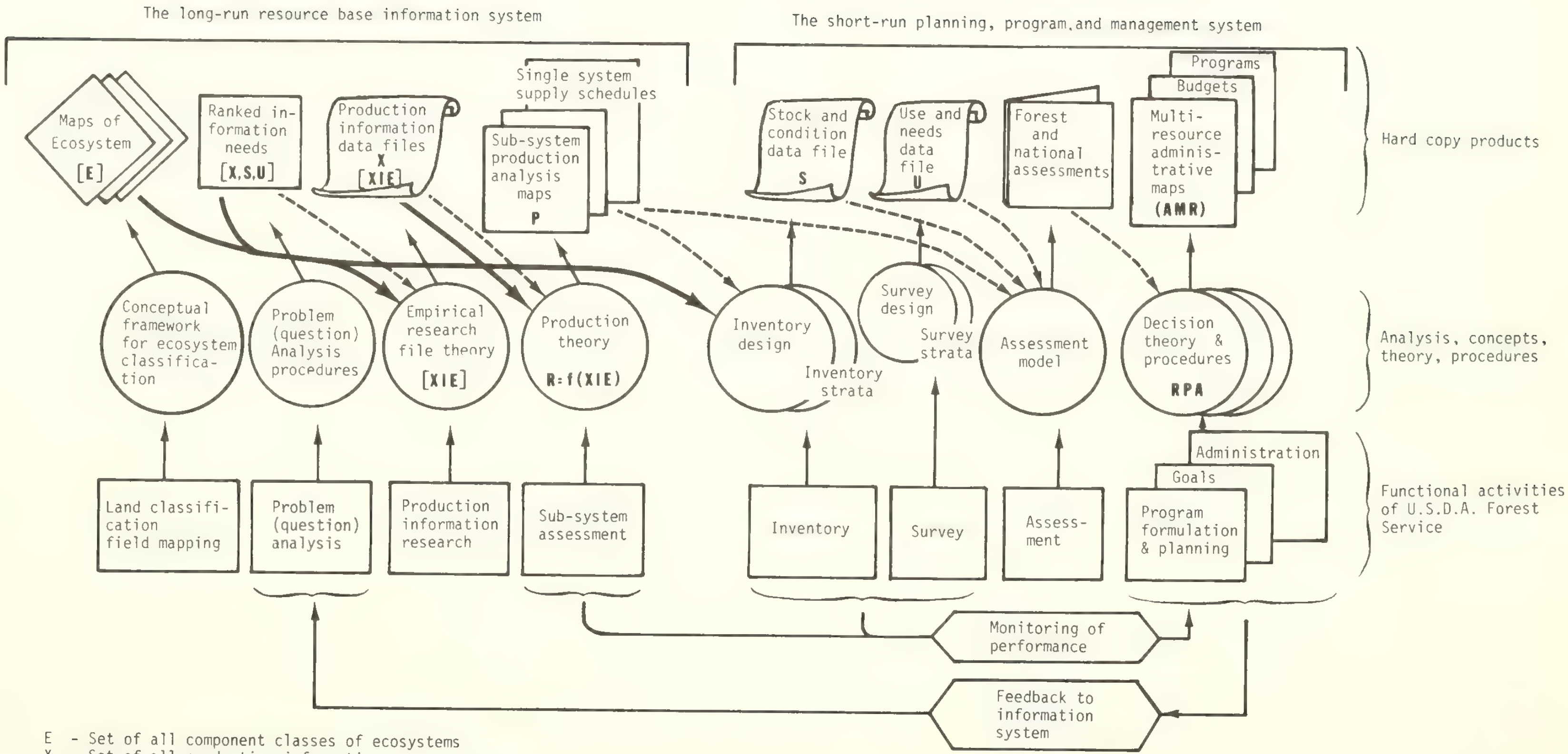
LAND-CLASSIFICATION MODEL

Traditionally, classifying and mapping land and aquatic resources has been used only to define for particular cases, not for stable attributes of ecosystems in general. It has provided a meaningful tool for specific information at particular locations for a limited time period, but the information gathered has not been generally useful or applicable to other locations.

The needed system will succeed or fail as it provides a useful, cost-effective vehicle to store and retrieve a wide range of relevant management information. It will have three basic parts: an identified set of information needs, a classification system, and a delivery system that relates the information to the classification system and delivers it in usable form to the manager.

How effective the system is — that is, does it work? — can only be determined by empirically testing the two critical assumptions, which it shares with all classification systems: that the system contains the needed information (and, of course, that the manager can ask the right questions); and that the types and precision levels of information needed by the manager can be related to (predicted by) the set of discrete classes for ecosystems.

This system must fit the needs at every level, from local to national, but because the local land manager has the most precise, place-specific, frequent, and varied needs, the system should be



E - Set of all component classes of ecosystems
X - Set of all production information
S - Set of all stock or current condition information
U - Set of all use, consumption and demand information
R - Set of mapped delineations for production analysis of sub-systems
AMR - The operational multi-resource management map showing land allocations to sub-system production and allocation of management treatments

Figure 3—Structure shows how a land-and-water classification system is related to the Forest and Rangeland Renewable Resources Planning Act and to a management system.

designed to treat him as the primary client.

Such a system will require much time and money for completion. It must therefore have a stable "building-block" structure, which means that each part of the system is permanent (that no new part will have to supersede an old), that it must be useful when partially completed, and that the most important parts should be built first.

The system should have the following characteristics:

1. *Component Classification* — A component-classification system allows great flexibility and a more universal applicability than any other. An integrated system, for example, pre-determines the way components are combined and makes value judgments, selecting only the situations it was designed for. A component system does not restrict the user to any particular component or set of components; he may choose what works best for him in his area, or try different components for better solutions, because the number of possible combinations and permutations resembles the continuum of the real world.

2. *Hierarchical Classification* — A hierarchical classification has different levels of different degrees of resolution or generalization. Each higher level is more generalized than those below. Each higher level is an aggregation of those and only those classes immediately beneath it; therefore, all classes are mutually exclusive. If you know one class at any level, you automatically know all others above it.

3. *Objective* — The boundaries should be permanently fixed so that generalizations can be made about the entire class; otherwise, marginal units might get into the wrong class as a result of interpretation or whim. Objectivity will eliminate interpretation and ensure that all users will make the same choice.

The system is described as it would be used by the local manager, who will conduct the primary inventory and assessment work to transform local ecosystem and economic and political reality into feasible system-production alternatives. That the local system can be aggregated to and disaggregated from the state, regional, and national levels makes it implicitly usable at the national level. The system would also handle the assessment of non-Forest Service lands.

The system may be represented graghically as three horizontal rows of eight components each (*fig. 3*). The top row is composed of "hard copy" products (maps, information files, etc.). The middle row represents a set of theories or analytical procedures. The bottom row is the functional activities. Bottom-to-top linkages show that a function works to produce hard copy, while left-to-right linkages show how each succeeding function draws on the previous hard copy to provide its own output.

The following list names the components this land-and-water classification system will need, with an abbreviated indication of their functions:

1. Land Classification — The function is mapping, and the product is a map or a tabular summary of area distribution.

2. Production Information Research — This function collects and compiles the production information and stores it in an information file.

3. Sub-System Assessment — This analyzes the resource base.

4. Inventory — Under a narrow definition, this collects information about the current stock, status, and condition of resources, *i.e.*, the information set.

5. Survey — This determines the rates, location, etc., related to resource-system output.

6. Assessment — This is a function of the scope and purpose spelled out by RPA; aggregates to the national from the forest level.

7. Program-Planning and Decision-Making — This sets goals, plans land use, involves public, and such.

8. Monitoring and Feedback — Mainly, this monitors the incremental information obtained from survey and inventory and evaluated at the program level.

At present the accounting of current and potential production is based on land delineations that are defined on current-use ownership, administration, and current conditions. Establishing this new system would shift that accounting to the permanent and potentially much more useful delineation defined on a land-and-water ecosystem base.

Costs would be high, both in money and in time, and the new system would greatly affect survey, inventory, and research. And yet the gains would be much greater. The first components to get are land classification, question analysis, production information research, and the sub-system assessment activity, along with their hard-copy results and information storage and retrieval technology.

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APPENDIX C–REPORT ON WORKSHOP D
OBJECTIVES AND REQUIREMENTS OF THE ACT

It was our opinion that the goals of Congress in passing this legislation were to obtain:

1. Better picture of overall program alternatives and their consequences;

2. Greater control of policies and budget making vis-à-vis the President and the Office of Management and Budget (OMB);

3. Basis for matching the Forest Service proposals

with those of other agencies; and

4. To minimize the number of special action issues and hassles they would have to resolve.

Similarly, we believe goals of the Forest Service in supporting the legislation and in implementing its requirements are to obtain:

1. Better picture of overall program alternatives and their consequences.

2. Greater control of policies and budget-making vis-à-vis the President and OMB;

3. A larger budget;

4. Insulate programs from sporadic attacks, and budgets from short-run fluctuations; and

5. To gain more visibility and support in Congress.

To achieve these purposes we suggest the Forest Service should develop a much more explicit analytical framework than the "analytical framework" of the current RPA. An explicit framework would permit sensitivity analyses which would reflect changes in *variables of immediate interest* to Congress and which are subject to policy changes. This framework would not only be able to handle the long-term requirements of the Act, but also provide qualitative and quantitative response information related to *short-term* contingencies.

We assume almost all phases of the assessment and program would be strengthened in the 1979-80 plan; and even further improved in 1989-90. Specifically, we would urge attention be given to the following phases of the assessment:

par (1) "An analysis of present and anticipated uses, demand for, and supply . . ." Conduct the analysis using a formal supply and demand model in a traditional economic framework. This model should contain a foreign trade as well as domestic sector.

par (2) "an inventory . . ." A formal benefit cost analysis is recommended for the evaluation of opportunities to improve yields of tangible and intangible goods and services from renewable resources.

par (3) "a description of Forest Service programs" . . . and an analysis of the relationship between these programs and responsibilities "to public and private activities" requires strengthening. Particularly, this should require formal joint planning at the secretarial level to determine national goals and output targets for each of the output systems (Recreation, Wildlife, Range, Timber, and Land and Water), subdivided into agency targets, and then submitted to Congress for modification and approval. This is essential to assure that Forest Service programming will be based on national and agency targets that are compatible with those of other federal agencies with major responsibilities for a Range, Recreation, etc. This may require additional legislation.

par (4) "a discussion of important policy considerations . . ." This is currently the weakest section of the assessment and therefore requires particular attention. Specifically, we recommend these analyses:

1. Various interpretations of the even flow timber harvesting policies, and its effects on price and output fluctuations in the public, private and international context.

2. Federal timber export and import policies.

3. Effect of public programs aimed at production of timber and other system outputs from private lands.

4. Improvements in social impact analysis of various system output configurations.

5. Effect of annual budget deviations from program requests.

6. Effect on lumber price fluctuations of National Forest sales of federal logs rather than stumpage.

7. Effects of various rationing devices for recreation, such as user fees, reservations, high concessionaire prices, etc.

8. Effects of various incentives to improve program implementations, such as budget reductions for districts which fail to fully implement programs; premiums for those which achieve program targets; and bidding by districts on forests for right to produce specific system outputs.

9. Opportunities to affect and/or alter demand for various forest outputs as an alternative method for "balancing" supply and demand relationships.

In addition, we recommend legislative modification of the assessment schedule, moving it forward 5 years to be able to take advantage of new census data, rather than using data 10 years old. We recommend proceeding with the 1980 assessment and then adjusting the schedule.

In developing future Forest Service program plans, in accordance with Section 3 of PL93-378, we recommend strengthening all phases, particularly . . .

par (2) for Program outputs, improve the estimates of costs and related benefits.

par (3) develop a much more comprehensive and useful discussion of priorities and array of Program opportunities.

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USDA FOREST SERVICE
GENERAL TECHNICAL
REPORT PSW- 22 /1977

TANOAK ... a bibliography for a promising species

Philip M. McDonald

McDonald, Philip M.

1977. **Tanoak . . . a bibliography for a promising species.** USDA Forest Serv. Gen. Tech. Rep. PSW-22, 8 p., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Lists 177 references, including most of the available citations on tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), with major emphasis on dendrology, synecology, diseases, chemical control, seasoning, and uses of the wood.

Oxford: 176.1 *Lithocarpus densiflorus:* (048.1)
Retrieval Terms: tanoak; *Lithocarpus densiflorus;* bibliography.

The Author

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The potential worth of tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) was recognized as early as 1908 when Sudworth[1] noted the "promise it gives of furnishing good commercial timber in a region particularly lacking in hardwoods." Abundant in northwestern California and southwestern Oregon (specifically in Del Norte, Humboldt, Mendocino, Curry, and Josephine Counties), the species extends southward in the California Coast Ranges to Santa Barbara County. It grows particularly well in the central Sierra Nevada, and is in plentiful supply in Butte and Yuba Counties, in central California.

The wood of tanoak has several outstanding attributes, not the least of which is appearance. Numerous tall rays give rotary-cut veneer and flat-grain surface lumber a striking appearance, resembling rift-sawed oak. The wood is tough and hard. It has outstanding strength, resists denting and abrasion, machines easily, and does not split when fasteners are used. In addition, it takes stains and finishes well, and forms strong joints with glues.

Ironically, native California hardwoods, and specifically tanoak, which could provide a major opportunity for increased wood and fiber production, are scarcely utilized. Although California has a variety of well established hardwood industries, raw material for them traditionally is imported from other sources. Recently, however, increased utilization of tanoak for pulp, prohibitive costs of rail transportation from east to west, and the dwindling supply of high quality hardwood sawlogs in eastern forests have prompted a new look at this species.

According to 1954 and 1968 surveys, the supply of tanoak sawtimber is 2.04 billion board feet in California and 1.52 billion board feet in Oregon. About 58 percent of this volume is in trees larger than 20.9 inches in breast-height diameter. This high proportion of large trees is significant because less than one-fifth of the hardwood sawtimber in the United States is 15 inches in diameter or larger and of grades 1 and 2.[2]

Seasoning used to be a problem, but reliable techniques are available now and are described extensively in the literature. The cold soda process works well and produces a good pulp.[3] Satisfactory offset printing and duplicating papers have been manufactured with mixtures of Douglas-fir and sulfate pulps of tanoak. Recently, tanoak and other hardwood species have been mechanically chipped in the woods and exported to Japan. The wood is ideally suited for pallets, flooring, industrial decking, and baseball bats. It is recommended for paneling, veneer, and plywood, and has been used for boat parts, crossties, and mine timbers. Suggested limitations to increased utilization are the scattered nature of the stands and the high amount of cull material in the trees.

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1956. **Strength and related properties of tanoak.** J. For. 54(7):458-462.

847. Rasmussen, Edmund F. (131)
1961. **Dry kiln operators manual.** U.S. Dep. Agric., Agric. Handb. 188, 197 p.

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1963. **Tanoak drying program and shrinkage characteristics.** Calif. Agric. 17(10):12-14.

830. Robinson, Dan D. (134)
1948. **Utilization of Oregon hardwoods.** Sch. For. Inf. Circ. 2, 22 p. Oreg. State Univ., Corvallis.

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231.4 Roy, D. F. (136)
1955. **Hardwood sprout measurements in northwestern California.** U.S. For-

est Serv. Calif. Forest and Range Exp. Stn. Res. Note 95, 6 p., Berkeley.

4. Roy, D. F. (137)
1956. **Killing tanoak in northwestern California.** U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 106, 9 p., Berkeley.

2.3 Roy, D. F. (138)
1957a. **A record of tanoak acorn and seedling production in northwestern California.** U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 124, 6 p., Berkeley.

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1957b. **Silvical characteristics of tanoak.** U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 22, 21 p., Berkeley, Calif.

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1962. **California hardwoods: Management practices and problems.** J. For. 60:184-186.

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1950. **Control of sprouting of tanoak and madrone stumps.** U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 74, 2 p. Berkeley, Calif.

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1962. **Chemicals for brush control in California reforestation.** U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 73, 14 p., Berkeley, Calif.

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1958. **Host fungus index for the Pacific Northwest. I. Hosts.** Wash. Agric. Exp. Stn. Circ. 335, 127 p.

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1956. **Improved utilization of western hardwoods by modern drying.** Forest Prod. J. 6:121-124.

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1954. **Forest cover types of North America.** 67 p. Soc. Am. For., Washington, D.C.

151. Stienecker, Walter, and Bruce M. Browning. (157)
1970. **Food habits of the western gray**

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166.1 Stuhr, Ernst T. (158)
1933. **Manual of Pacific Coast drug plants.** 189 p. Lancaster, Pa.

174. Sudworth, George B. (159)
1908. **Forest trees of the Pacific slope.** 441 p. U.S. Gov. Print. Off., Washington, D.C.

530. Sundahl, William E. (160)
1966. **Crown and tree weights of madrone, black oak and tanoak.** USDA Forest Serv. Res. Note PSW-101, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

174. Thomas, J. H. (161)
1961. **Flora of the Santa Cruz Mountains of California, a manual of the vascular plants.** 434 p. Stanford Univ. Press, Palo Alto, Calif.

847. Torgeson, O. W. (162)
1950. **Kiln-drying schedules for 1-inch laurel, madrone, tanoak, and chinquapin.** U.S. Forest Serv. Forest Prod. Lab. Rep. R1684, 24 p.

181.351 Trappe, James M. (163)
1960. **Some probable mycorrhizal associations in the Pacific Northwest. II.** Northwest Sci. 34:113-117.

414. Tschirley, Fred H. (164)
1957. **Undesirable woody plants.** Res. Progr. Rep. 17th Ann. West. Weed Control Conf. p. 41-50, March 20-21, Boise, Idaho.

165. Tucker, John M., William E. Sundahl, (165) and Dale O. Hall.
1969. **A mutant of** *Lithocarpus densiflorus.* Madroño 20(4):221-225.

443. U.S. Department of Agriculture. (166)
1960. **Index of plant diseases in the United States.** U.S. Dep. Agric., Agric. Handb. 165, 531 p.

906. U.S. Department of Commerce. (167)
1968. **The Hoopa Valley Reservation hardwood study report.** Econ. Devel. Admin. 162 p.

905. U.S. Forest Service. (168)
1954. **Forest statistics for California.** U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Release 25, 66 p., Berkeley.

812. U.S. Forest Service. (169)
1955. **Wood handbook.** U.S. Dep. Agric., Agric. Handb. 72, 528 p.

174. Van Dersal, William R. (170)
1938. **Native woody plants of the United States, their erosion-control and wildlife values.** U.S. Dep. Agric. Misc. Publ. 303, 362 p.

443. Wagener, Willis W. (171)
1963. **Judging hazard from native trees in California recreational areas: a guide for professional foresters.** USDA Forest Serv. Res. Paper PSW-P1, 29 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley.

182. Waring, R. H. (172)
1969. **Forest plants of the eastern Siskiyous: their environmental and vegetational distribution.** Northwest Sci. 43(1):1-17.

182. Whittaker, R. H. (173)
1954. **The ecology of serpentine soils. IV. The vegetational response to serpentine soils.** Ecology 35(2): 275-288.

182. Whittaker, R. H. (174)
1960. **Vegetation of the Siskiyou Mountains, Oregon and California.** Ecol. Monogr. 39:279-338.

542. Wiant, Harry V., Jr., and (175) William S. Berry.
1965. **Cubic-foot volume and tarif access tables for tanoak in Humboldt County, California.** Div. Nat. Resour. For. Rep. 2, 10 p. Humboldt State Coll., Arcata.

232.3 Wolf, C. B. (176)
1945. **California wild tree crops.** Rancho Santa Ana Bot. Gard., Calif., Santa Ana Canyon. 68 p.

443. Yarwood, C. E., and M. W. Gardner. (177)
1972. **Powdery mildews favored by agriculture.** Phytopathology 62(7):799.

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

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The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

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USDA FOREST SERVICE
GENERAL TECHNICAL
REPORT PSW- 23 /1977

FIFTY YEARS OF FORESTRY RESEARCH:

annotated bibliography of the Pacific Southwest Forest and Range Experiment Station,

1926-1975

Aitro, Vincent P., compiler

1977. **Fifty years of forestry research: annotated bibliography of the Pacific Southwest Forest and Range Experiment Station, 1926-1975.** USDA Forest Serv. Gen. Tech. Rep. PSW-23, 250 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Lists 2905 publications, with annotations and subject and author indexes, issued during the first 50 years of the Pacific Southwest Forest and Range Experiment Station (formerly the California Forest and Range Experiment Station), headquartered at Berkeley, California.

Oxford: 945.4(048.1)(794)

Retrieval Terms: forest management research, forest insect and diseases research, forest fire research, forest environment research, forest economics and forest products research, management sciences research, California, Hawaii, California Forest and Range Experiment Station, Pacific Southwest Forest and Range Experiment Station.

Compiler:

VINCENT P. AITRO is supervisory librarian, Information Services Group, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California.

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FIFTY YEARS OF FORESTRY RESEARCH: annotated bibliography of the Pacific Southwest Forest and Range Experiment Station, 1926-1975

VINCENT P. AITRO, Compiler

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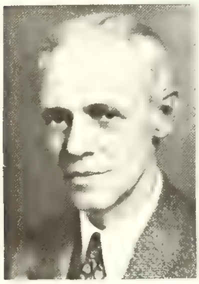

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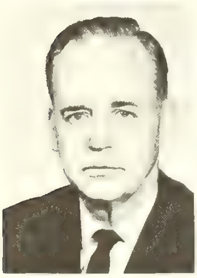

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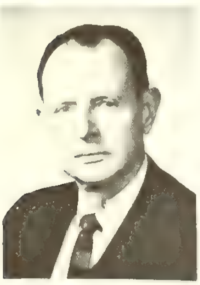


R. Keith Arnold
1957-1963

What is now known as the Pacific Southwest Forest and Range Experiment Station was established on July 1, 1926 as the California Forest Experiment Station. Its first quarters were a modest four rooms in Hilgard Hall on the campus of the University of California in Berkeley. The campus was to be the Station's home for the next 33 years, as it moved to Giannini Hall in 1930, and then in 1948 to the new forestry building, Mulford Hall, where it remained for 11 years. These years on campus fomented and nurtured rapport and cooperative relationships with University administrators and forestry faculty and researchers that continue today.

Early in the Station's history, the Station was renamed the California Forest and Range Experiment Station, as its program expanded to include research in rangeland management.

On April 15, 1959, the Station's administrative boundaries were extended to include Hawaii, which had just become the Nation's 50th State. As it began research on forest-resource problems in Hawaii and other areas in the Pacific Basin, the Station was given its present name of the Pacific Southwest Forest and Range Experiment Station.

In the same year, the Station moved to its current headquarters at 1960 Addison Street in Berkeley, just a few blocks away from its long-time home on the University of California campus.

In contrast to the modest quarters in Hilgard Hall in 1926, the Station now maintains modern research centers in strategic locations in California and Hawaii.

Facilities in northern California include the headquarters at Berkeley, which houses not only administrative offices but laboratories for a number of research units; the Institute of Forest Genetics, at Placerville, the first and oldest such institute in the United States; a unit at Davis for field evaluation of chemical insecticides; the Central Sierra Snow Laboratory at Soda Springs; a major field unit concerned with silviculture of Sierra Nevada conifers at Redding; and the Redwood Sciences Laboratory at Arcata.

In southern California, a field unit at Fresno is concerned with environmental research on range-wildlife relationships and threatened and endangered species; a unit at Glendora is concerned with management of chaparral and related ecosystems; and the Forest Fire Laboratory is located at Riverside.

Research in Hawaii and the Pacific Basin is centered at the Institute of Pacific Islands Forestry in Honolulu.

In addition to these facilities, much of the Station's research is conducted in outdoor laboratories that include the San Joaquin Experimental Range in the foothills of the west-side Sierra Nevada, and nine Experimental Forests, rang-

Range Experiment Station...
ears

ing from the Redwood Experimental Forest, a northern California drainage of coast redwood and Douglas-fir, to the chaparral-covered North Mountain Experimental Forest in southern California. Research is also carried out through cooperative agreement on other Federally administered lands, on State lands, and on privately-owned lands.

As the scope of its research responsibilities grew, there was commensurate growth in the Station's staff. Today, the research staff includes more than 100 scientists, representing 20 or more disciplines. The scope of the current program is epitomized by the diversity of the research staff, which includes foresters, geneticists, botanists, biologists, plant physiologists, plant pathologists, entomologists, geologists, hydrologists, and meteorologists. The list continues with ornithologists, wildlife biologists, range management specialists, soil scientists, landscape architects, sociologists, economists, mathematicians, operations research analysts, and computer specialists.

These researchers work in teams known as Research Work Units or on special Research and Development Programs. Currently, about 25 research teams specialize in such areas as forest genetics, timber culture and forest management, forest fire and related sciences, forest economics, forest insect and disease control, recreation and land-use planning, range management, watershed management, wildlife habitat, anadromous fisheries, and threatened and endangered species.

The 2 905 publications cited in this volume are more than a bibliography of research literature published by the Station in its first 50 years. Knowledgeable readers scanning the citations decade by decade will not only be able to trace the growth and progress of the Station since it was established in 1926, they will also be able to trace trends in forestry and forestry research that parallel the Nation's changing concerns for our environmental resources. Because research is evolutionary rather than revolutionary, the trends are subtle, but they are discernible.

In 50 years, the Station has changed in size and in the scope and breadth of its research. But its commitment to the public, to resource managers, and to the scientific community remains the same—to provide technology that will ensure wise use and conservation of our forest resources and to anticipate needs and provide leadership that will be truly responsive to national concerns about those resources.

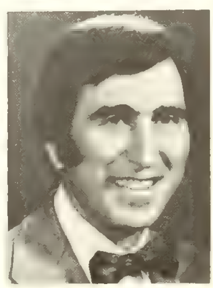
ROBERT Z. CALLAHAM
Director

John R. McGuire
1963-1967

Robert D. McCulley
1967-1971

Harry W. Camp
1971-1973

Robert W. Harris
1973-1976



Robert Z. Callaham
1976-

FOREWORD

The publications in this bibliography are arranged under the broad subject categories shown in the Table of Contents. The publications are listed alphabetically, by author, under each category. To gain an overview of publications in a broad area, such as **Forest Management**, consult all citations under that heading.

The Subject Index will lead to key topics discussed or cited in the publications that may not be ascertained through the titles. An Author Index lists all authors alphabetically. In both Author and Subject Indexes, the numbers shown refer to the number of the publication in the bibliography.

The listing of publications was generally limited to those published either as Station serial or non-serial publications, U.S. Department of Agriculture publications, in proceedings of symposiums, or in journals. Progress reports, reports written in fulfillment of certain cooperative agreements, or other materials written for administrative purposes were not included.

Despite efforts to meticulously check all entries, the scope of the task was such that errors may have been inadvertently overlooked. There also may be errors in omission of bonafide publications. It would be appreciated if any errors or omissions noted are brought to the attention of the Publications Section, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

Many of the publications listed here are available free of charge from the Station. Availability of publications will vary, however, with new publications in stock and many of the older publications out of print. Requests for publications should be directed to the Publications Section at the address above.

FOREST MANAGEMENT

Silviculture

1. Amidon, Elliot L., and Garth S. Akin
1968. *Dynamic programming to determine optimum levels of growing stock.* Forest Sci. 14(3):287-291, illus.
For determining optimal levels during a rotation, a one-dimensional dynamic computer program proved to have both analytical and computational advantages over traditional methods.

2. Amidon, Elliot L.
1974. *Computer mapping in forest resource management.* In *Use of computers in forestry.* p.41-56. Peter J. Fogg and Thomas D. Keister, ed. Louisiana State Univ., Baton Rouge.
Describes progress being made to automate data processing in natural resources management by developing computerized geographic information systems.

3. Averell, James L., John C. Crowell, Clarence R. Quick, and Gilbert H. Schubert.
1955. *Sugar pine management—an annotated bibliography.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 12, 56 p. illus. Berkeley, Calif.
Describes publications that have a bearing on the growing of sugar pine for timber production.

4. Baron, Frank J.
1960. *Biochemical changes associated with stock storage.* West. Forest Nurserymen's Seventh Biennial Meet. Haugen, Mont. Proc.:66-69
Describes how to estimate the internal "readiness" of plants for cold storage.

5. Baron, Frank J., and Gilbert H. Schubert.
1961. *California cone crop—1961.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 188, 9 p., illus. Berkeley, Calif.
Field reports indicated a poor crop on nearly all species of forest trees except sugar pine, Douglas-fir, red fir, white fir, and redwood, which had scattered medium to heavy crops.

6. Baron, Frank J.
1962 *California cone crop—1962.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 203, 8 p., illus. Berkeley, Calif.
Sugar pine had a bumper crop, incense-cedar failed, and scattered medium-sized crops were reported on ponderosa and Jeffrey pines, Douglas-fir, and the true firs.

7. Baron, Frank J.
1962. *Effects of different grasses on ponderosa pine seedling establishment.* U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Stn. Res. Note 199, 8 p., illus. Berkeley, Calif.
Poor initial establishment of seedlings planted on a burned area was associated with certain species of grass.

8. Baron, Frank J.
1963. *California cone crop—1963.* U.S. Forest Serv. Res. Note PSW-25, 11 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A June frost in the northern part of the state killed the majority of cones on Douglas-fir, incense-cedar and fir, leaving medium-sized crops on redwood, ponderosa pine, and Jeffrey pine.

9. Baron, Frank J., and Gilbert H. Schubert.
1963. *Seed origin and size of ponderosa pine planting stock grown at several California nurseries.* U.S. Forest Serv. Res. Note PSW-9, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Among west-side Sierra Nevada sources, seeds from zones above 4000 feet yielded smaller seedlings than seeds from lower zones, but larger seedlings than east-side sources.

10. Baron, Frank J., and G. H. Schubert.
1963. *Seedbed density and pine seedling grades in California nurseries.* U.S. Forest Serv. Res. Note PSW-31, 11 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Two seasons after hand-planting, field survival of stock grown at 50 and 10 per square foot was 62 and 83 percent, whereas survival after machine planting with comparable stock was 72 and 92 percent.

11. Baron, Frank J., and Carl W. Fowler.
1964. *Sugar pine seedling size—a reflection of seed handling.* Tree Planters' Notes 66:22-25.
The sturdiest planting stock developed from seeds from carefully handled cones of the preceding year's crop whereas routine handling of cones from the same crop, or the use of seeds stored from 2 to 6 years, yielded

definitely smaller stock and fewer plantable trees.

12. Baron, Frank J., Eamor C., Nord, A. B. Evanko, and William Makel.
1966. *Seeding conifers and buffer crops to reduce deer depredation.* U.S. Forest Serv. Res. Note PSW-100, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes technique of alleviating deer browsing by interplanting shrubs and herbaceous plants with ponderosa pine.

13. Bentley, Jay R., David A. Blakeman, and Stanley B. Carpenter.
1971. *Recovery of young ponderosa pines damaged by herbicide spraying.* USDA Forest Serv. Res. Note PSW-252, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Recovery was more complete in plantations with younger pines than in plantations with older pines and dense stands of vigorous brush.

14. Blankensop, C. M., and Robert Z. Callaham.
1960. *Rooting cuttings from Douglas-fir, white fir, and California red fir Christmas trees.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 160, 3 p. Berkeley, Calif.
Outlines procedure and results for rooting branch-tips from young trees, with best results obtained by using the medium of Tahoe sand for Douglas-fir, and sponge rock for white fir.

15. Boe, Kenneth N.
1960. *Redwood "test tube" forest.* West. Conserv. J. 17(2):16-18.
Describes research plans, including tests of clearcutting, selection, and shelterwood in conversion of old-growth to managed stands, as well as preliminary results on sprouting and seed dispersal.

16. Boe, Kenneth N.
1960. *Research at the Redwood Experimental Forest.* 12 p., illus., U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Outlines the salient features of the resource on the Redwood Experimental Forest, the studies in progress, and first results.

17. Boe, Kenneth N.
1961. *Redwood seed dispersion in old-growth cutovers.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 177, 7 p., illus. Berkeley, Calif.
Abundant sound seed of high viability was produced for natural reproduction in selection, shelterwood, and clearcuttings.

18. Boe, Kenneth N.
1964. *Silvicultural research plans for redwood and Douglas-fir forests.* 9 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Principal objectives for California's north coastal area are control of forest establishment, competition, and growth on the timber lands for production of quantity and quality wood.

19. Boe, Kenneth N.
1965. *Natural regeneration in old-growth redwood cuttings.* U.S. Forest Serv. Res. Note PSW-94, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
On the first clearcutting at the Redwood Experimental Forest, stumps began to sprout before the logging was finished and first seed had germinated 3 months after the cuttings were finished.

20. Boe, Kenneth N.
1966. *Stocking control in the redwood region—too many trees?* West. Reforestation Coord. Comm. Proc. 1966:42-44.
Describes the stocking of young-growth stands of various ages, and gives examples of what current thinnings are being made for control of the growing stock.

21. Boe, Kenneth N.
1968. *Cone production, seed dispersal, germination in old-growth redwood cut and uncut stands.* USDA Forest Serv. Res. Note PSW-184, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Provides guides for such silvicultural practices as choosing seed trees, getting the most out of seedfall by timing site preparation, and scheduling cone collection.

22. Boe, Kenneth N.
1973. *Redwood,* In *Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, p. 24-26.
Summarizes information on the culture of old-growth and young growth redwood.

23. Boe, Kenneth N.
1974. *Growth and mortality after regeneration cuttings in old-growth redwood.* USDA Forest Serv. Res. Paper PSW-104, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Basal area and cubic volume increment were lower on the shelterwood cuttings than on either the selection cuttings or the uncut stands.

24. Boe, Kenneth N.
1974. *Thinning promotes growth of sprouts on old-growth redwood stumps.* USDA Forest Serv. Res. Note PSW-290, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Sprouts on old-growth stumps more than doubled in diameter after 5 years when heavily thinned and increased by one-half when moderately thinned.

25. Boe, Kenneth N.
1975. *Natural seedlings and sprouts after regeneration cuttings in old-growth redwood.* USDA Forest Serv. Res. Paper PSW-111, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif.
All cuttings, including clearcutting, shelterwood, and selection, regenerated satisfactorily; cuttings were mainly of redwood, but also included Douglas-fir and other conifers.

26. Buck, John M., Ronald S. Adams, Jerold Cone, M. Thompson Conkle, and William J. Libby.
1970. *California tree seed zones.* 3 p., illus. Calif. Reg., U.S. Forest Serv., San Francisco, Calif., and Calif. Div. Forestry, Sacramento, Calif.
Describes a coding system for seed identification, suggests rules for using seed identified by the new criteria, and recommends a standardized labeling system.

27. Burgan, Robert E.
1971. *A spacing trial in tropical ash, an interim report.* USDA Forest Serv. Res. Note PSW-226, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The 8-year remeasurement suggests that spacing had not yet produced a statistically significant effect on diameter or height growth.

28. Burgan, Robert E., and Wesley H. C. Wong, Jr.
1971. *Species trials in the Waiakea Arboretum, tree measurements in 1970.* USDA Forest Serv. Res. Note PSW-240, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Survival, growth, and tree quality were measured for 84 introduced tree species planted during 1956-1960 in a cleared rain forest area near Hilo, Hawaii.

29. Carpenter, Stanley B., and George B. Richmond.
1965. *Five-year-measurements of unit 3, Waiakea Arboretum, Hawaii.* U.S. Forest Serv. Res. Note PSW-63, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Measurements of several introduced tree species showed various rates of survival and general suffering due to shallow soil conditions and competitive wild vegetation.

30. Carpenter, Stanley B.
1965. *Survival and five-year growth in unit 4, Waiakea Arboretum, Hawaii.* U.S. Forest Serv. Res. Note PSW-88, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Growth measurements and survival counts made of introduced tree plantings showed various rates of survival, with competition from wild vegetation as the main cause of mortality.

31. Chapman, Roger C.
1963. *Pruning labor in shortleaf-loblolly pine.* J. For. 61(2):144-145, illus.
Shows how pruning time can be estimated by point sampling procedures and reveals the basal area to be the single variable most highly correlated with pruning time.

31. Corbett, Edward S.
1962. *Ponderosa pine reproduction in relation to seed supply at Challenge Experimental Forest.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 195, 3 p. Berkeley, Calif.
Gives results of an attempt to select young growth seed trees to produce estimated quantities of seed and discusses stocking in cut-over plots.

33. Corson, C. W., and H. A. Fowells
1952. *Here's how—a guide to tree planting in the California pine region.* Calif. Forest and Range Exp. Stn. Misc. Paper 8, 26 p. Berkeley, Calif.
Describes methods for successful planting of coniferous trees in California.

34. Cosens, Richard D.
1952. *Epicormic branching on pruned white fir.* J. For. 50(12):939-940.
Concludes that pruning of white fir to increase production of clear wood is economically infeasible.

35. Cossitt, F. M.
1960. *A plan for a centralized nursery for the state of Hawaii.* 40 p., illus., U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Analyzes present production methods for forest planting stock by the Hawaii Division of Forestry; recommends two suitable sites for a central nursery, nursery design, and operating methods.

36. Davis, James B.
1969. *Elementary allocation models—how to use them in forestry operations.* USDA Forest Serv. Res. Note PSW-187, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The potential savings in time and money by using allocation techniques are demonstrated in three simple techniques that can be used to solve a wide range of problems.

37. Dunning, Duncan.
1922. *Relation of crown size and character to rate of growth and response to cutting in western yellow pine.* J. For. 20(4):379-389.
Trees were grouped according to combinations of external crown features and then used to estimate the probable response each tree would make after release by cutting.

38. Dunning, Duncan.
1923. *Some results of cutting in the Sierra forests of California.* U.S. Dep. Agric. Bull. 1176, 27 p. Gov. Print. Off., Washington, D.C.
Concludes that the best results are obtained by selecting trees free from defects with bark color and texture characteristic of immaturity, pointed tops, dense dark green foliage, and crown length equal to 60 percent or more of the total height.

39. Dunning, Duncan.
1926. *Predicting the second cut in National Forest management plans.* J. For. 24(7):745-790.
Suggests the formulation of cutting tables derived from increment borings and records based on inventory cruises of cut-over land to predict the volume that will be available.

40. Dunning, Duncan.
1928. *A tree classification for the selection forests of the Sierra Nevada.* J. Agric. Res. 36(9):755-771.
Proposes a new classification system and then compares seven classes of *Pinus ponderosa* based on age, degree of dominance, crown development, and vigor.

41. Dunning, Duncan.
1928. *Woodland thinning by preserving better trees often profitable.* U.S. Dep. Agric. Yearb. 1928:624-625.
Presents a method for the selection of trees to make beneficial thinnings which relieve crowding, allow more complete use of the soil, and improve the quality of timber produced.

42. Dunning, Duncan.
1929. *Silviculture and research in the virgin forests of California.* Stockh. Verhardl. Int. Kongr. Forst. Versuchsanst. p. 441.
Describes the topography, climate, vegetation, silvicultural practices, and investigations to improve logging operations and restore cut-over lands.

43. Dunning, Duncan
1933. *Site index curves for mixed selection stands in Region 5.* 3 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes the procedure and application of a plan to establish curves based on the average total height of dominant trees for age-classes up to 650 years.

44. Dunning, Duncan, and B. M. Kirk.
1939. *The Burney Spring plantation: a reforestation experiment in the brushfields of northern California.* 59 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Compared in terms of normally developed living trees, the stripping treatment was much the poorest; burning was intermediate, and burning and stripping the best.

45. Dunning, Duncan.
1940. *Direct seeding experiments in California.* In *Experimental direct seeding by the Forest Service.* p. 18-24. M.A. Huberman, ed. Washington, D.C.
Discusses past work using direct seeding as means of reforesting burns and waste areas, and mentions present studies measuring response of seedlings to site treatments, effects of rodents, and influence of seed source.

46. Dunning, Duncan
1942. *A site classification for the mixed-conifer selection forests of the Sierra Nevada.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 28, 21 p., Berkeley, Calif.
Curves based on height-age relationship are presented in order to establish a single criterion of site as nearly as possible like the one now in use for volume surveys, growth forecasting, and other forestry work.

47. Dunning, Duncan.
1949. *A sugar pine regeneration cutting experiment.* West Coast Lumberman 76(3):62, 64.
Describes and estimates results of an old-growth conversion which required three cuttings during the conversion period for the release of reproduction and advance growth.

48. Fowells, Harry A., and R. Keith Arnold.
1939. *Hardware cloth seed-spot screens reduce high surface soil temperatures.* J. For. 37(10):821-822.
Screens not only provide protection against animals but produce a favorable shade as well.

49. Fowells, Harry A.
1943. *The effect of certain growth substances on root-pruned ponderosa pine seedlings.* J. For. 41(9):685-686.

Data indicates that indoleacetic acid was relatively ineffective in promoting root initiation, and vitamin B_1 had little effect on the growth of roots or tops.

50. Fowells, Harry A.
1944. *Site preparation as an aid to sugar pine regeneration.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 28, 21 p. Berkeley, Calif.
Brush cover was removed in cut-over stands of sugar pine in anticipation of a good seed crop, but natural reproduction was less successful than seed spotting and planting on the cleared areas.

51. Fowells, Harry A., and B. M. Kirk.
1945. *Availability of soil moisture to ponderosa pine.* J. For. 43(8):601-604.
Results indicate the importance of root condition for initial field establishment of planting stock and the ability of established ponderosa pine to live in spite of adverse soil moisture conditions.

52. Fowells, Harry A.
1946. *Forest tree seed collection zones in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 51, 5 p. Berkeley, Calif.
Presents a map as a guide for planting stock in an environment comparable to that of the location in which the seed was collected, and for simplifying the keeping of records of seed lots.

53. Fowells, Harry A.
1949. *Cork oak planting tests in California.* J. For. 47(5):357-365.
Describes a series of field experiments conducted to find the establishment conditions, and gives recommendations on how and where to plant cork oak for commercial growing.

54. Fowells, Harry A.
1949. *An index of ripeness for sugar pine seed.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 64, 5 p. Berkeley, Calif.
The strong relation between specific gravity of the cone and germination of the seed offers an objective method of accepting or rejecting the cones.

55. Fowells, Harry A., and Gilbert H. Schubert.
1951. *Natural reproduction in certain cutover pine-fir stands of California.* J. For. 49(3):192-196.
Reports that despite a predominance of pine seed trees before logging, natural regeneration of cutover lands favors firs and cedars.

56. Fowells, Harry A., and Gilbert H. Schubert.
1951. *Recent direct seeding trials in the pine region of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 78, 9 p. Berkeley, Calif.
Reports that the direct seeding of conifers in California is econonically infeasible due to the necessity for costly programs to protect the seeds from rodents.

57. Fowells, Harry A.
1953. *The effect of seed and stock sizes on survival and early growth of ponderosa and Jeffrey pine.* J. For. 51(7):504-507.
Ponderosa and Jeffrey pine seedlings and trees from small seeds were consistently smaller and less hardy than seedlings and trees from larger seeds.

58. Fowells, Harry A., and Gilbert H. Schubert.
1953. *Planting-stock storage in the California pine region.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 3, 12 p. Berkeley, Calif.
Experiments proved that ponderosa and Jeffrey pine seedlings can be stored under artificial refrigeration for up to 6 months at 36° with a 90 percent survival rate.

59. Fowells, Harry A.
1953. *Regeneration problems and research in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 10, 4 p. Berkeley, Calif.
Poor climate, a short planting season, rodents, and invasive brush species hamper attempts at artificial regeneration.

60. Fowells, Harry A., and Gilbert H. Schubert.
1955. *Planting trials with transpiration retardants in California.* Tree Planters' Notes 20:19-22.
Transpiration retardants were not effective in increasing survival of sugar pine, Jeffrey pine, and ponderosa pine planting stock.

61. Fowells, Harry A., and Gilbert H. Schubert.
1956. *Seed crops of forest trees in the pine region of California.* U.S. Dep. Agric. Tech. Bull. 1150, 48 p., illus.
Summarizes 28 years of seed production of sugar pine, ponderosa pine, and white fir, and interprets this information for application to cutting practices and seed collection.

62. Furniss, M. M., and William E. Hallin.
1955. *Development of high-risk trees in ponderosa and Jeffrey pine stands following sanitation-salvage cutting.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 94, 2 p. Berkeley, Calif.
High-risk trees made up 7.7 percent of the stand volume 16 to 17 years after sanitation-salvage cutting, compared with 17.2 percent of the virgin stand before the cutting.

63. Gordon, Donald T.
1959. *Ten-year observations on pruned ponderosa and Jeffrey pine.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 153, 4 p. Berkeley, Calif.
Half the live crown or six-tenths of the total height of tree can be pruned without adverse effects on growth.

64. Gordon, Donald T.
1962. *Growth response of east side pine poles to removal of low vegetation.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn Res. Note 209, 3 p. Berkeley, Calif.
The pines grew faster when perennial bunchgrass was destroyed than when bunchgrass plus broad-leaved shrubs or broad-leaved shrubs alone were eliminated.

65. Gordon, Donald T.
1970. *Natural regeneration of white and red fir . . . influence of several factors.* USDA Forest Serv. Res. Paper PSW-58, 32 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A large quantity of sound seed, mineral soil seedbed, and probably some degree of shade during first year were found to be most advantageous to seedling establishment.

66. Gordon, Donald T.
1970. *Shade improves survival rate of outplanted 2-0 red fir seedlings.* USDA Forest Serv. Res. Note PSW-210, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif.
Seedlings artificially shaded during first growing season had a significantly higher survival rate than unshaded seedlings.

67. Gordon, Donald T., and Douglass F. Roy.
1973. *Red fir—white fir.* In *Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, p. 26-28.
Summarizes silvicultural information on the mixed forests of red fir and white fir, which cover nearly 3 million acres on the Sierra Nevada, southern Cascade Range, and northern Coast Range.

68. Gordon, Donald T.
1973. *Released advance reproduction of white and red fir...growth, damage, mortality.* USDA Forest Serv. Res. Paper PSW-95, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Seedling and sapling height growth before logging was only 0.1 to 0.2 foot per year; 5 years after cutting, seedling and sapling height growth had accelerated to about 0.5 to 0.8 foot annually.

69. Griffin, James R.
1966. *Digger pine seedling response to serpentinite and non-serpentinite soil.* Ecology 46(6):801-807, illus.
Seedlings from the serpentinite soil collection locality made relatively poor growth in the serpentinite soil.

70. Hall, Dale O.
1963. *The effect of advance growth on ponderosa pine seedling mortality at Challenge Experimental Forest.* U.S. Forest Serv. Res. Note PSW-8, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
As advance-growth stocking increased from 11 to 49 square feet, seedling mortality increased from 4 to 32 percent; whereas a comparable increase in the stocking of seed trees over 20 inches in d.b.h. did not increase mortality.

71. Hall, Dale O.
1964. *Hog ringer speeds seed trap construction.* J. For. 62:39, illus.
An upholsterer's hog-ringer increased production of 1 foot-square wire seed traps by 25 percent.

72. Hall, Dale O.
1967. *Broadcast seeding ponderosa pine at Challenge Experimental Forest—a progress report.* U.S. Forest Serv. Res. Note PSW-144, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports that hand baiting and sowing patch cuts in December 1965 yielded 880 to 2540 pine seedlings per acre by July 1966, and gives costs per hundred seedlings per acre.

73. Hallin, William E.
1951. *Unit area control in California forests.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 77, 8 p. Berkeley, Calif.
"Unit area control" breaks up planning units into naturally defined areas for use in forest management in the Sierra Nevada.

74. Hallin, William E.
1954. *Unit area control—its development and application.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 16, 10 p. Berkeley, Calif.
Unit area control focuses attention on the group structure of forests and the necessity for providing for regeneration at appropriate times and places in order to create proper distribution of age-classes.

75. Hallin, William E.
1956. *Planting ponderosa pine is a good investment.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 104, 5 p. Berkeley, Calif.

Estimates the present worth at different rates of interest for ponderosa plantations on sites ranging in productivity from poor to excellent.

76. Hallin, William E.
1956. *Pruning ponderosa and Jeffrey pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 115, 4 p. Berkeley, Calif.
Shows the maximum heights to which crop trees may be pruned at different stand densities and tree diameters.

77. Hallin, William E.
1959. *The application of unit area control in the management of ponderosa-Jeffrey pine at Blacks Mountain Experimental Forest.* U.S. Dep. Agric. Tech. Bull. 1191, 96 p., illus.
Summarizes 18 years of operation of the area to study and demonstrate silvicultural management of the east-side pine type.

78. Harris, Richard W., W. Douglas Hamilton, William B. Davis, Andrew T. Leiser.
1969. *Pruning landscape trees.* Univ. Calif. Agric. Ext. Serv., Berkeley, and Davis, Calif. Bull. AXT-288, 13 p., illus.
This compendium of existing procedures and practices can be used as a guide to capitalize on the natural characteristics of each tree species.

79. Harris, Richard W., Andrew T. Leiser, and William B. Davis.
1969. *Staking landscape trees.* Univ. Calif. Agric. Ext. Serv., Berkeley, and Davis, Calif. Bull. AXT-311, 13 p., illus.
Describes different staking techniques for providing adequate, flexible support for windy situations and reasonable protection with little or no tree injury.

80. Hennes, Leroy C., Michael Irving, and Daniel I. Navon.
1971. *Forest control and regulation...a comparison of traditional methods and alternatives.* USDA Forest Serv. Res. Note PSW-231, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The use of three harvest methods—Timber Resource Allocation model, formulas, and area-volume check—is illustrated with inventory drawn from a National Forest in California.

81. Hill, C. L.
1934. *Forestry in land use.* 4 p. Paper for land use series, station KPO, San Francisco.
The forester must be mindful of the values of each use of land and strive to make the most productive utilization for the social and economic welfare of the people.

82. Horton, Jerome S.
1950. *Effect of weed competition upon survival of planted pine and chaparral seedlings.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 72, 6 p. Berkeley, Calif.
Experiments demonstrated that weeding of plots was necessary prior to planting of seedlings.

83. Hughes, B. O., and Duncan Dunning.
1949. *Pine forests of California.* U.S. Dep. Agric. Yearb. 1949:352-358.
Discusses briefly several silvicultural aspects of California's National Forests ranging from composition and ownership to marketing and management.

84. Jemison, George M.
1955. *Forest management made easy.* Forest Prod. J. 5(2):40-42A.
Outlines California's chief forest-product utilization problems and urges that forest managers work together to solve these problems.

85. Kimbrough, E. F.
1949. *Making paper tubes for plant propagation.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 59, 5 p. Berkeley, Calif.
Describes how to make lightweight paper tubes for culturing ornamental plants or tree seedlings.

86. Krugman, Stanley L., and R. M. Echols.
1963. *Modified tree band to foil cone-harvesting squirrels.* U.S. Forest Serv. Res. Note PSW-35, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Explains how to make and install an expandable aluminum tree band that will prevent cone harvesting by squirrels.

87. Krugman, Stanley L., E. C. Stone, and R. V. Bega.
1965. *The effects of soil fumigation and lifting date on the root-regenerating potential of Monterey pine planting stock.* J. For. 63(2):114-119.
Root-regenerating potential determined by a system of destructive sampling was found for seedlings grown in fumigated and non-fumigated beds, and results showed a seasonal trend similar to that previously reported for ponderosa pine and Douglas-fir.

88. Krugman, Stanley L.
1965. *The use of soil fertilizers in the management of a seed production area and a seed orchard in California—a progress report.* Fourth Calif. Forest Soil Fert. Conf. Proc.:69-76, illus.
Reports varying results of inorganic fertilizers applied

to a knobcone pine seed orchard and a ponderosa pine seed production area in order to stimulate cone production.

89. Krugman, Stanley L.
1966. *Artificial ripening of sugar pine seeds.* U.S. Forest Serv. Res. Paper PSW-32, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif.
Only after the second week of August could immature seeds be brought to maturity, thereby providing the possibility of developing a practical method for commercial operation.

90. Krugman, Stanley L. and E. C. Stone.
1966. *The effect of cold nights on the root-regenerating potential of ponderosa pine seedlings.* Forest Sci. 12(4):451-459.
Suggests the possibility of using cold nights to precondition stock so that it would have a high root-regenerating potential on specific planting dates.

91. Lanner, Ronald M.
1961. *A deodar cedar plantation in southern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 175, 4 p. Berkeley, Calif.
Examination of a small plantation 31 growing seasons after its establishment showed relatively rapid growth in this unfavorable environment.

92. Lanner, Ronald M.
1961. *Living stumps in the Sierra Nevada.* Ecology 42(1):170-173.
Examines evidence of root grafts, in 25 living stumps and discusses silvical implications of root-grafting in regard to growth after thinnings and the spread of root rots.

93. Lanner, Ronald M.
1962. *Some factors affecting rooting of Douglas-fir and true fir cuttings.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 202, 5 p., illus. Berkeley, Calif.
Bottom heat and rooting medium influenced rooting, but treatment with indolebutyric acid did not.

94. LeBarron, Russell K.
1956. *We can have sugar pine—without fire.* Sierra Club Bull. 41(10):84-86.
Concludes that sugar pine owes its perpetuation primarily to such qualities as long life and large size and points to the need for blister rust control and planting of old burns and cutovers.

95. LeBarron, Russell K.
1957. *Silvicultural possibilities of fire in northeastern Washington.* J. For. 55(9):627-630.
Suggests how some less well known facts about fire can be used in managing forest lands.

96. LeBarron, Russell K.
1958. *What is unit area control?* J. For. 56(9):662-663.
Describes a method of management based upon the recognition of forest condition classes, which are useful for planning sulvicultural treatment, inventory, and forest regulation.

97. LeBarron, Russell K.
1962. *Eucalypts in Hawaii; a survey of practices and research programs.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 64, 24 p., illus. Berkeley, Calif.
Discusses eucalyptus species in Hawaii—how they are grown and present research.

98. LeBarron, Russell K.
1962. *Experimental designs for simple planting and other reforestation experiments.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 74, 13 p., illus. Berkeley, Calif.
Briefly describes procedures to follow in planning, conducting, and analyzing field experiments and illustrates several experimental designs.

99. LeBarron, Russell K.
1965. *Growing Norfolk-Island Christmas trees in Hawaii.* Univ. Hawaii Coop. Ext. Serv. Misc. Publ. 23, 12 p., illus.
Experience in production by the Hawaii Division of Forestry and advice on methods of culture are summarized.

100. Libby, William J., and M. Thompson Conkle.
1966. *Effects of auxin treatment, tree age, tree vigor, and cold storage on rooting young Monterey pine.* Forest Sci. 12(4):484-502, illus.
Rooting percentage and number of roots per rooted cutting declined with increasing age of the parent trees, but were unaffected by tree vigor.

101. Liddicoet, A. R., and E. F. Kimbrough.
1947. *Pinus: Propagation of experimental stock.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 56, 8 p. Berkeley, Calif.
Describes nursery techniques of preparation, storage, layout, planting and care of seedlings designed to facilitate statistical testing.

102. Liddicoet, A. R., E. F. Kimbrough, and E. J. Carpender.
1953. *Ponderosa pine plantation pruning.* J. For. 51(4):275-276.

Pruning of ponderosa pines on plantations reduces fire hazard and facilitates measurement of trees.

103. Liddicoet, A. R.
1956. *Humidity control unit for greenhouses and propagating beds.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 112, 3 p., illus. Berkeley, Calif.
Describes construction and operation of an inexpensive control unit used at the Institute of Forest Genetics, at Placerville, Calif.

104. Lindquist, James L.
1974. *Sampling redwood seedling and sprout regeneration, an improved technique.* U.S. Forest Serv. Res. Note PSW-294, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A combined quadrat and point-sample method may be used to develop estimates of per-acre regeneration.

105. Lynch, Donald W.
1967. *Silviculture and special use interests.* Soc. Am. For. Proc. 1966:78-80.
Describes special areas that require new methods, and suggests some silvicultural treatments which are compatible with the maintenance of natural beauty and recreational requirements.

106. Lynch Donald W.
1973. *Mechanical thinning of young conifer stands.* Trans. Am. Soc. Agric. Eng. 16(1):34-36, illus.
Mechanical thinning of over dense conifer stands is a promising treatment to be used as a first operation in a program of stand rehabilitation.

107. McCulley, Robert D.
1970. *Thinning in conifers of the Western United States.* Proc. IUFRO Meet., on Thinning and Mechanization, Stockholm, Sweden 1969:49-57.
Continuing changes in markets and in the technology bearing on utilization of small trees to make thinning more feasible can be expected.

108. McCulley, Robert D.
1970. *Thinning practice for conifers in the Lake States and the Northeast in the United States.* Proc. IUFRO Meet., on Thinning and Mechanization, Stockholm, Sweden 1969:58-62.
Although precommercial thinning may all but disappear in plantations, there may be an increasing need for it on natural stands in the future.

109. McDonald,Philip M.
1966. *Seed fall and regeneration from a group selection cut—first year results.* U.S. Forest Serv. Res. Note PSW-113, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The opening sizes for the three species studied affected seed fall and resulting first year generation and are therefore responsible for subsequent differences in seedling growth and species composition.

110. McDonald, Philip M.
1969. *Ponderosa pine seed-tree removal reduces stocking only slightly.* J. For. 67(4):226-228, illus.
After trees on the Challenge Experimental Forest, California, were removed, the mean reduction in seedling stocking was 3.8 percent or about 212 seedlings per acre.

111. Mirov, N. T.
1935. *Two centuries of afforestation and shelterbelt planting on the Russian steppes.* J. For. 33(12):971-973.
Reviews the general meteorological and soil conditions of the Russian steppes and silvicultural practices for comparison with prairie projects in the Midwestern United States.

112. Mirov, N. T.
1936. *A note on germination methods for coniferous species.* J. For. 34(7):719-723.
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113. Mirov, N. T.
1937. *Application of growth hormones in forest nurseries.* Planting Q. 6(3):18.
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114. Mirov, N. T., and Charles J. Kraebel.
1937. *Collecting and propagating the seeds of California wild plants.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 18, 29 p. Berkeley, Calif.
Describes the collection, extraction, germination, treatment, and storage of seeds, and provides a table of cultural data on 255 species of California flora.

115. Mirov, N. T., and Charles J. Kraebel.
1939. *Collecting and handling seeds of wild plants.* U.S. Civ. Conserv. Corps. For. Publ. No. 5, 42 p. U.S. Gov. Print. Off., Washington, D.C.
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116. Mirov, N. T.
1940. *Additional data on collecting and propagating*

the seeds of California wild plants. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 21, 17 p. Berkeley, Calif.
A table listing 178 different species, with data on seed and culture, supplements Research Note 18.

117. Mirov, N. T.
1940. *Tested methods of grafting pines.* J. For. 38(10):768-777.
Results from several methods of grafting scions of pines on the stocks of pines belonging to distant taxonomic groups indicate that grafting has possibilities as a method of propagation.

118. Mirov, N. T.
1943. *Can branch cuttings of conifers develop into straight trees?* J. For. 41(5):369-370.
Experiments indicate that cuttings of some species do not develop as well as seedlings, but that Monterey pine can be grown very well from slips.

119. Mirov, N. T.
1944. *Experiments in rooting pines in California.* J. For. 42(3):199-204.
Several experiments were conducted involving the variables of age, branches used, treatments, season, physiological condition of the shoots, temperature of the rooting medium, and the relation between the temperature of the atmosphere and that of the rooting medium.

120. Mirov, N. T., and W. C. Cumming.
1945. *Propagation of cork oak by grafting.* J. For. 43(8):589-591.
Experiments in California show that cork oak can be grafted on native oaks, both in the greenhouse and in the field.

121. Mirov, N. T.
1946. *Viability of pine seed after prolonged cold storage.* J. For. 44(3):193-195.
Seeds of 21 species of pine kept in cold storage for periods ranging from 5 to 15 years were still viable.

122. Mirov, N. T., and Mark Blankensop.
1958. *A note on the propagation of Torreya californica.* J. Calif. Hortic. Soc. 19:15.
Whereas the seeds germinate slowly, propagation of this rare conifer by cuttings is easy.

123. Mirov, N. T., and Mark Blankensop.
1959. *A note on rooting cuttings of dawn redwood.* J. Calif. Hortic. Soc. 20(1):9-10.
Describes how this tree can easily be propagated with mature-wood cuttings and outlines a treatment that improves rooting.

124. Mirov, N. T., and Egon Larsen.
1949. *Possibilities of Mexican and Central American pines in world reforestation projects.* The Caribb. For. 19(3, 4):43-49, illus.
Points out value of these pines in reforestation, indicates ecological and administrative difficulties in collecting seeds, and suggests ways to organize seed collections.

125. Navon, Daniel I.
1967. *Computer-oriented systems for wildland management.* J. For. 65(7):473-479, illus.
Computer-oriented systems, including the linear programming approach to land management, can aid in the rational allocation of wildland resources.

126. Navon, Daniel I., and Richard J. McConnen.
1967. *Evaluation forest management policies by parametric linear programming.* U.S. Forest Serv. Res. Paper PSW-42, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The technique of parametric linear programming is explained and applied to complex policy decision problems.

127. Navon, Daniel I.
1969. *Activity analysis in wildland management.* The Ann. of Reg. Sci. 3(2):75-84.
By restricting the production possibilities to a finite number of management alternatives, allocation activities can be used to develop operational management plans.

128. Navon, Daniel I.
1971. *Timber RAM...a long range planning method for commercial timber lands under multiple-use management.* USDA Forest Serv. Res. Paper PSW-70, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Timber RAM can produce cutting and reforestation schedules and related harvest and economic reports.

129. Navon, Daniel I., and Henry W. Anderson.
1972. *Modern techniques in planning the management of wildland resources.* Proc. Jt. FAO/USSR Int. Symp. on For. Influences and Watershed Manage., Moscow, USSR 1970:359-368.
Techniques for applying inventory information, basic research results, and systems analysis to the planning of wildlands are discussed.

130. Navon, Daniel I.
1973. *Forest management as seen by the computer.*

Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc., Portland, Oreg. 1973:162-164, illus.
The exceptional capabilities of the computer can make it highly useful in solving well-defined problems that can be attacked by a rigorously logical procedure.

131. Neal, Robert L., Jr.
1967. *Sprouting of old-growth redwood stumps...first year after logging.* U.S. Forest Serv. Res. Note PSW-137, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Some sprouting characteristics reveal useful information for evaluating reproduction potential, possible silvicultural treatments, and problems for additional research.

132. Neal, Robert L., Jr.
1975. *Ponderosa pine seeding trials in west-side Sierra Nevada clearcuts: some early results.* USDA Forest Serv. Res. Note PSW-305, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The best results were obtained on northerly aspects on unburned mechanically disturbed seedbeds, with a high proportion of exposed mineral soil and high rates of seed application.

133. Nelson, Robert E.
1960. *Silk-oak in Hawaii—pest or potential timber.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 47, 5 p., illus. Berkeley, Calif.
Opposing points of view are discussed, and the opportunity for timber production from silk-oak is pointed out.

134. Nelson, Robert E.
1965. *A record of forest plantings in Hawaii.* U.S. Forest Serv. Resour. Bull. PSW-1, 18 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes the extensive, 60-year-old tree planting program to facilitate appraisal of introduced species for forestry use and to guide further research.

135. O'Regan, William G., Lucas Arvanitis, and Ernest M. Gould, Jr.
1966. *Systems, simulation, and forest management.* Proc. Soc. Am. For. Annu. Meet. 1965:194-198, illus.
Reports research and some preliminary results on a systems approach to aid forest management decisions.

136. O'Regan, William G.
1974. *The statistician's viewpoint.* Proc. Inventory Design and Analysis Workshop, Fort Collins, Colo. 1974:10-12, illus.
The statistician should be full colleague in the planning process and be aware of the objectives, procedures, and pitfalls.

137. Oliver, William W.
1970. *Cacodylic acid for precommercial thinning in mixed-conifer stands shows erratic results.* USDA Forest Serv. Res. Note PSW-224, 3 p. Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif.
Cacodylic acid, injected during the growing season at dosages recommended by the manufacturer, did not adequately thin two of three stands.

138. Oliver, William W., and Robert F. Powers.
1971. *Early height growth of ponderosa pine forecasts dominance in plantations.* USDA Forest Serv. Res. Note PSW-250, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Dominant trees in 10 California plantations reached breast height ½ year sooner than codominants and 1 ½ years sooner than intermediates, regardless of site quality.

139. Oliver, William W.
1972. *Growth after thinning ponderosa and Jeffrey pine pole stands in northeastern California.* USDA Forest Serv. Res. Paper PSW-85, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Thinning stands (6-8 inches d.b.h.) on Meyer Site Classes IV and V land (site index 65-80) stimulates diameter and height growth.

140. Oliver, William W.
1972. *Height intercept for estimating site index in young ponderosa pine plantations and natural stands.* USDA Forest Serv. Res. Paper PSW-276, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a technique for obtaining site index in ponderosa pine stands less than 20 years old.

141. Oliver, William W.
1974. *Seed maturity in white fir and red fir.* USDA Forest Serv. Res. Paper PSW-99, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Embryo length/cavity length ratio was the most useful index of maturity; cone specific gravity also was correlated with nearly all measures of seed germination.

142. Person, Hubert L.
1937. *Commercial planting on redwood cut-over lands.*

U.S. Dep. Agric. Circ. No 434, 40 p. U.S. Gov. Print. Off., Washington, D.C.
Concludes that successful planting is possible at moderate cost if new-logged areas are planted promptly and due care is given to choice of stock.

143. Person, Hubert L.
1942. *Increment of residual redwoods.* J. For. 40(12):926-929.
Uses the rate of increase in the basal area to estimate the yields of stands as a guide for selective cutting.

144. Person, Hubert L., and William E. Hallin.
1942. *Natural restocking of redwood cutover lands.* J. For. 40(9):683-688.
Concludes that much of the land is seriously understocked, that even distribution of healthy seed trees is the only dependable means of reproduction from a natural seed source, and that slash and litter removal encourages natural reproduction.

145. Pickford, Gerald D., and Russell K. LeBarron.
1960. *A study of forest plantations for timber production on the island of Hawaii.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 52, 17 p., illus. Berkeley, Calif.
Forest plantations of *Eucalyptus robusta, Eucalyptus saligna, Fraxinus udhei,* and *Toona ciliata* var. *australis,* ages 20 to 38 years, were examined to determine rates of growth and adaptability to various habitats as a guide to future planting.

146. Pickford, Gerald D.
1962. *Opportunities for timber production in Hawaii.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 67, 11 p., illus. Berkeley, Calif.
Discusses Hawaii's need for locally-grown timber and the state's potential for filling this need.

147. Powers, Robert F., and Harry V. Wiant.
1970. *Sprouting of old growth coastal redwood stumps on slopes.* Forest Sci. 16(3):339-341, illus.
Vigor of dominant sprouts was positively correlated with clump density, with vertical concentration occurring at lower positions on stumps.

148. Powers, Robert F.
1972. *Estimating site index of ponderosa pine in northern California...standard curves, soil series, stem analysis.* USDA Forest Serv. Res. Note PSW-265, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Of the four curves tested, those by Dunning and Reineke seem superior in describing height growth trends of dominant trees in the first 50 to 60 years of stand development.

149. Powers, Robert F.
1972. *Site index curves for unmanaged stands of California black oak.* USDA Forest Serv. Res. Note PSW-262, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports curves that should be useful in determining the growth potential of this species in northern California.

150. Powers, Robert F., Kani Isik, and Paul J. Zinke.
1975. *Adding phosphorus to forest soils: storage capacity and possible risks.* Bull. Environ. Contam. and Toxicol. 14(3):257-264.
Two contrasting California forest soils were studied, and a simple method for quantifying phosphorus storage capacity is described.

151. Powers, Robert F.
1975. *Evaluating fertilizer programs using soil analysis, foliar analysis, and bioassay methods.* Proc. Servicewide Silviculture Work Conf., Sacramento, Calif. Oct. 21-25, 1974, p. 124-162, illus. Div. Timber Manage., USDA Forest Serv., Washington, D.C.
Evaluates three major methods of gauging forest need for—and response to—nutrient change and describes a six-stage program for National Forests leading to operational fertilization.

152. Richardson, S. D.
1959. *Germination of Douglas-fir seed as affected by light, temperature, and gibberellic acid.* Forest Sci. 5(2):174-181, illus.
Germination at low temperatures was speeded by long photoperiod (16 to 24 hours of light per day) or by gibberellic acid.

153. Richmond, George B.
1963. *Species trials at the Waiakea Arboretum, Hilo, Hawaii.* U.S. Forest Serv. Res. Paper PSW-4, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif.
Includes survival counts of 84 introduced tree species planted during 1956-1960 as well as growth measurements for 5- and 6-year-old plantings.

154. Roof, J. B.
1941. *Growing California's two wax myrtles.* Calif. Hortic. Soc. J. 2(3):167-172.
Myrica californica easily adapts to a wide variety of soils, thrives on much or little water and in sun or shade; whereas *Myrica hartwegii* can be shifted from granitic sand to light garden loam and does well in a lightly shaded spot.

155. Roy, Douglass F.
1953. *Douglas-fir regeneration...a selected and annotated bibliography for use in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 1, 10 p. Berkeley, Calif.
Lists 84 references covering the period 1909-1952, and includes annotations.

156. Roy, Douglass F.
1953. *Effects of ground cover and class of planting stock on survival of transplants in the eastside pine type of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 87, 6 p. Berkeley, Calif.
Experiments indicate survival rates for various types of planting stock are best in bare soil free of stones and worst in soil with heavy vegetative cover.

157. Roy, Douglass F., and Gilbert H. Schubert.
1953. *K-screen seed spots.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 88, 2 p. Berkeley, Calif.
K-screen barriers must be improved before they are recommended for use in protecting seeds and seedlings in the Sierra Nevada.

158. Roy, Douglass F.
1955. *The Clements growth prediction charts for residual stands of mixed conifers in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 9, 13 p., illus. Berkeley, Calif.
These alinement charts can be used to estimate gross increment, ingrowth, and loss in stands of the Sierra Nevada.

159. Roy, Douglass F.
1955. *Don't plant close to unbarked logs!* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 101, 1 p., illus. Berkeley, Calif.
About 3 years after logging, cull logs begin to slough off large sheets of bark which can cover and smother seedlings.

160. Roy, Douglass F.
1955. *Oregon limits of California tree seed collection zones.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 93, 3 p., illus. Berkeley, Calif.
Collection zones are extended into southern Oregon in order to permit obtaining seed from somewhat larger areas with assurance that seed will produce trees suited to their environment.

161. Roy, Douglass F.
1956. *Research in the redwood region.* The Ukiah News, Logging Edition, May 24, 1956, Sec. 4:8.
Summarizes forest management research activities and lists some of the problems facing the managers of timber lands which can be answered by research.

162. Roy, Douglass F.
1956. *Salvage logging may destroy Douglas-fir reproduction.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 107, 5 p., illus. Berkeley, Calif.
Destruction of seedlings, which amounted to 80 percent of the 2000 seedlings per acre present before logging in northwestern California, can be reduced by careful prompt logging.

163. Roy, Douglass F.
1957. *Forest tree planting—here's how in the redwood-Douglas-fir region of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 20, 31 p., illus. Berkeley, Calif.
Tells where, when, what, and how to plant to obtain good results.

164. Roy, Douglass F.
1957. *Seed spot tests with tetramine-treated seed in northern California.* J. For. 55(6):442-445, illus.
An acetone-tetramine treatment inhibited germination of Douglas-fir but not of ponderosa pine and protected seeds from rodents; a dextrin-tetramine treatment did not protect seeds and inhibited germination of ponderosa pine.

165. Roy, Douglass F.
1958. *Forest management research in the Redwood-Douglas-fir region of California, a summary of foresters' views on research needs.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 24, 17 p., illus. Berkeley, Calif.
The most important research needs are site classification and yield tables, information on the results of various cutting methods, a tree vigor classificaiton for redwood, more knowledge regarding regeneration, and ways to improve and fully utilize material harvested from young-growth redwood stands.

166. Roy, Douglass F.
1959. *Small seed traps perform well in the Douglas-fir type of California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 150, 7 p., illus. Berkeley, Calif.
During a year of heavy seedfall, 1-square-foot seed traps performed as well as 8.2-square-foot traps; performance was not affected by distance from seed source.

167. Roy, Douglass F.
1960. *Deer browsing and Douglas-fir seedling growth in northwestern California.* J. For. 58(7):518-522, illus.

A six year study of Columbian black-tailed deer browsing on planted seedlings revealed damage inversely related to the amount of preferred plants and also showed seedling growth seriously reduced when browsing was repeated annually.

168. Roy, Douglass F.
1960. *Douglas-fir seed production and dispersal in northwestern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 49, 22 p., illus. Berkeley, Calif.
Reports that seed crops are variable, may be scanty for periods of several years and generally poor in quality, and that amount of seed dispersal decreases with increased distance from seed source.

169. Roy, Douglass F.
1961. *Seed spotting with endrin-treated Douglas-fir seed in northwestern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 61, 12 p., illus. Berkeley, Calif.
A formulation of endrin, arasan, asphalt, and aluminum dust protected seed against seed-eating rodents.

170. Roy, Douglass F.
1962. *California hardwoods: management practices and problems.* J. For. 60(3):184-186.
Effective management for red alder, tanoak, and California black oak requires information on growth and yield, growth habits, and inherited characteristics, development of coppice management skills, control of seed-eating animals, and exclusion of fire.

171. Roy, Douglass F.
1963. *Instructions and codes for recording forest tree seed information in California.* 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Complements item 172 below.

172. Roy, Douglass F.
1963. *A system for recording forest tree seed lot information in California.* U.S. Forest Serv. Res. Note PSW-7, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Provides a means of recording information concerning the collection site, seed trees, seed collection, method of handling the seed lot, and disposition of the seed.

173. Roy, Douglass F.
1966. *Effects of a transpiration retardant and root coating on survival of Douglas-fir planting stock.* U.S. Forest Serv. Tree Planters' Notes 79:10-12.
Reports results of tests in which seedlings were treated with Foli-gard, a transpiration retardant, and Rutex 59, a water absorbing root coating.

174. Roy, Douglass F.
1974. *Arbutus menziesii* Pursh. Pacific madrone. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 226-227, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

175. Roy, Douglass F.
1974. *Cercis* L. Redbud. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 305-308, illus.
See item 174 above.

176. Roy, Douglass F.
1974. *Lithocarpus densiflorus* (Hook & Arn.) Rehd. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 512-514, illus.
See item 174 above.

177. Roy, Douglass F.
1974. *Torreya* Arn. Torreta. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 815-816, illus.
See item 174 above.

178. Schubert, Gilbert H.
1952. *Germination of various coniferous seeds after cold storage.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 83, 7 p. Berkeley, Calif.
Seeds of *Abies* and *Libocedrus* had low viability after 3 to 6 years while seeds of *Cupressus* and *Pinus* retained viability for 10 to 20 years.

179. Schubert, Gilbert H.
1953. *Ponderosa pine cone cutting by squirrels.* J. For. 51(3):202.
Concludes that pine squirrels may cause enough loss of seed to hamper natural regeneration.

180. Schubert, Gilbert H.
1953. *A trial of three chemicals as rodent repellents in direct seeding.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 84, 2 p. Berkeley, Calif.
Sodium fluoroacetate, red lead, and zinc phosphate proved ineffectual as repellants, although all three were effective as poisons.

181. Schubert, Gilbert H.
1954. *Viability of various coniferous seeds after cold storage.* J. For. 52(6):446-447.
Seed of many conifers collected in large quantities during good seed years will retain high viability for intervals sufficiently long to tide over the poor seed years.

182. Schubert, Gilbert H.
1955. *California cone crop—1955.* U.S. Forest Serv. California Forest and Range Exp. Stn. Res. Note 97, 2 p., illus. Berkeley, Calif.
The crop sizes of 15 different species are summarized by species, seed zone or county, and abundance.

183. Schubert, Gilbert H.
1956. *California cone crop – 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 110, 5 p., illus. Berkeley, Calif.
The crops were generally good for the first time in several years, except for incense-cedar, which was the only major species with no cones throughout most of its range.

184. Schubert, Gilbert H.
1956. *Early survival and growth of sugar pine and white fir in clear-cut openings.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 117, 6 p., illus. Berkeley, Calif.
More white fir than sugar pine seedlings were killed or damaged by freezing and browsing, thus giving sugar pine a headstart in the race for dominance.

185. Schubert, Gilbert H.
1956. *Effects of fertilizer on cone production of sugar pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 116, 4 p., illus. Berkeley, Calif.
Over a four-year period, fertilization with ammonium phosphate increased production three-fold.

186. Schubert, Gilbert H.
1957. *California cone crop—1957.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Res. Note 126, 5 p., illus. Berkeley, Calif.
The crops of a few species were medium to heavy in some seed zones, but generally crops were nonexistent or very light.

187. Schubert, Gilbert H.
1958. *California cone crop—1958.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 142, 5 p. Berkeley, Calif.
Cone production was rated as medium or less except for a few species which had heavy crops in some seed zones, but even these crops varied considerably in size.

188. Schubert, Gilbert H., and Frank J. Baron.
1959. *California cone crop—1959.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 155, 7 p., illus. Berkeley, Calif.
Good crops were predicted in only a few localities for 1959 with a general outlook for seed even worse than that experienced in 1958.

189. Schubert, Gilbert H., and Karl B. Lanquist.
1959. *Mist sprayer improves seeding harvester.* Tree Planters' Notes 38:19-20, illus.
Describes a mist sprayer attachment designed to keep seedling roots moist during lifting in the nursery.

190. Schubert, Gilbert H., and Douglass F. Roy.
1959. *Tests of sandwich planting and the mechanical planting hole digger in California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 151, 10 p., illus. Berkeley, Calif.
Planting conifer seedlings with roots encased between two pieces of a stiff, water-absorbent, fibrous material did not improve survival; the mechanical planting-hole digger offered some improvement over conventional methods.

191. Schubert, Gilbert H., and Frank J.Baron.
1960. *California cone crop—1960.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 164, 8 p., illus. Berkeley, Calif.
Prospects for a good crop were the best since 1956 with over half of the field reports indicating the potential crop as medium or better.

192. Schubert, Gilbert H., John M. Buck, and Anthony B. Evanko.
1960. *Rangeland drill used in reforestation in California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 42, 4 p., illus. Berkeley, Calif.
Preliminary results indicate that the drill can be regulated to drop pine seed at a desirable rate for direct seeding.

193. Schubert, Gilbert H., and Harry A. Fowells.
1964. *Sowing rates for reforestation by the seed-spotting method.* U.S. Forest Serv. Res. Note PSW-44, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Guides based on theoretical probabilities are presented to help determine number of seeds to sow per spot and number of spots required per acre to obtain acceptable stocking.

194. Schubert, Gilbert H., and Frank J. Baron.
1965. *Nursery temperature as a factor in root elongation on ponderosa pine seedlings.* U.S. Forest Serv. Res. Note PSW-66, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Greenhouse and nursery studies suggest that graphs of effective day and night temperatures provide a convenient method to compare nursery sites and to evaluate the effects of temperature on seedling root growth.

195. Siggins, H. W.
1928. *Sustained yield forest management, what it means to the California farmer.* Timberman 29(8):186, 188.
Offers suggestions for the lumberman and the public to regulate cutting and secure sustained yield on Sierra Nevada lands.

196. Siggins, H. W.
1928. *Tree crops may be wind sown at distance from the seed trees.* U.S. Dep. Agric. Yearb. 1928:586-587.
Describes a series of tests performed to find the distance seeds of certain species will be carried by winds of different velocities, and presents a table with factors to be used in estimating distance.

197. Stark, N. B.
1965. *Natural regeneration of Sierra Nevada mixed conifers after logging.* J. For. 63(6):456, 457, 460-461.
Results from 119 permanent quadrats and 468 temporary quadrats at the Stanislaus-Tuolumne Experimental Forest show that when logging preceded a good seed fall, 67 percent of the total reproduction established in the first year remained after 12 years.

198. Stockwell, Palmer.
1943. *Cork oak culture.* 4 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes the temperature, soil, shade, and moisture requirements of *Quercus suber* and the best methods of cultivation.

199. Stone, Edward C., and J. Holt.
1950. *A rapid method of separating seed of chamise (Adenostoma fasciculatum) from the duff.* Ecology 31(1):149.
Pinus lambertiana seeds pollinated with *P. armandi* and *P. koraiensis* pollen were cultured *in vitro* to facilitate germination.

200. Stone, Edward C., and Gilbert H. Schubert.
1959. *The physiological condition of ponderosa pine (Pinus ponderosa* Laws. *) planting stock as it affects survival after cold storage.* J. For. 57(11):837-841.

Planting stock lifted in late fall and early winter for overwinter storage and trees given a long period to achieve "physiological hardening" in the nursery were able to withstand long periods of cold storage.

201. Stone, Edward C., and Gilbert H. Schubert.
1959. *Ponderosa pine planting stock.* Calif. Agric. 13(3):11-12.
Preliminary results indicated that trees lifted during November and December at the Mt. Shasta Nursery for overwinter storage had a better chance for survival than stock lifted in September or October.

202. Stone, Edward C., and Gilbert H. Schubert.
1959. *Root regeneration by seedlings.* Calif. Agric. 13(2):12, 14.
Describes the methods used to study the ability of ponderosa pine seedlings to regenerate an extensive root system.

203. Stone, Edward C., and Gilbert H. Schubert.
1959. *Root regeneration of ponderosa pine seedlings lifted at different times of the year.* Forest Sci. 5(4):322-332.
Root elongation and root initiation showed a distinct seasonal periodicity and were affected by soil temperature.

204. Stone, Edward C., and Gilbert H. Schubert.
1959. *Seasonal periodicity in root regeneration on ponderosa pine transplants—a physiological condition.* Soc. Am. For. Proc. 1958:154-155.
The greatest root activity occurred at soil temperatures of 20° C and 25° C with greater root initiation and growth at lower temperatures in the spring than in the fall.

205. Stone, Edward C., Gilbert H. Schubert, Rolf W. Benseler, and others.
1963. *Variation in the root regenerating potentials of ponderosa pine from four California nurseries.* Forest Sci. 9:217-225, illus.
Results indicate a seasonal fluctuation in the regenerating potential; this supports earlier studies by confirming the inadequacy of any morphological grading system when the physiological condition is unknown.

206. Stone, Edward C., and James L. Jenkinson.
1970. *Influence of soil water on root growth capacity of ponderosa pine transplants.* Forest Sci. 16(2):230-239, illus.
In every test environment used in this study, from highly favorable to marginal, the root growth capacity peak was easily identified and occurred at the same nursery lifting date.

207. Stone, Edward C., and James L Jenkinson.
1971. *Physiological grading of ponderosa pine nursery stock.* J. For. 69(1):31-33, illus.
Describes an inexpensive system that will enable nurserymen to predict seedling root growth for specific planting dates.

208. Storie, R. Earl, and A. E. Wieslander.
1949. *Rating soils for timber sites.* Soil Sci. Soc. Am. Proc. 13:499-509.
Presents preliminary timber rating charts derived from studies on the soil-site relationships of dominant wildland soils.

209. Strothmann, Rudolph O., and J. Henry Doll.
1968. *Growth of Douglas-fir seedlings in a north-coast California nursery under four fertilizer regimes.* Tree Planters' Notes 19(3):6-8.
Granular, slow-release types of fertilizers rototilled into the soil did not produce larger, heavier, or better balanced 2-0 seedlings than those produced by the use of soluble fertilizers applied twice per year through the irrigation system.

210. Strothmann, Rudolph O.
1971. *Douglas-fir survival and growth in response to spring planting date and depth.* USDA Forest Serv. Res. Note PSW-228, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Evaluation of results after 3 growing seasons showed that none of the special planting modifications significantly improved survival over that of normal planting.

211. Strothmann, Rudolph O.
1971. *Germination and survival of Douglas-fir in northern California...effects of time of seeding, soil type, and aspect.* USDA Forest Serv. Res. Note PSW-245, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Sowing in November or December resulted in significantly more seedlings than sowing in February or March with more seedlings established on fine-textured soils of predominantly reddish color than on coarser-textured gray-brown soils.

212. Strothmann, Rudolph O.
1972. *Douglas-fir in northern California: effects of shade on germination, survival, and growth.* USDA Forest Serv. Res. Paper PSW-84, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Shade did not significantly improve the survival of planted trees (either 1-0 or 2-0 age class); good survival was probably due to a combination of other factors.

213. Strothmann, Rudolph O.
1972. *Douglas-fir reforestation on severe sites in northern California.* Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc. 1972:117-120.
Shade is decidedly beneficial if the aim is to obtain regeneration from direct seeding, but seems to be less important in planting.

214. Sundahl, William E.
1974. *Fine cleaning of small seeds by static electricity.* Tree Planters' Notes 25(2):2, illus.
Static electricity successfully separates small seeds from chaff of equal size.

215. Sundling, H. L., A. C. McIntyre, and A. L. Patrick.
1932. *Effect of soil reaction on the early growth of certain coniferous seedlings.* Am. Soc. Agron. J. 24(5):341-351.
An alkaline soil will inhibit development; the best growth occurred between pH values of 4 to 6.

216. Tackle, D., and Douglass F. Roy.
1953. *Site preparation as related to ground cover density in natural regeneration of ponderosa pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 4, 13 p. Berkeley, Calif.
Proper site preparation aids seed germination and seedling survival, and minimizes the period required to assure a new stand.

217. Teeguarden, Dennis E., and Donald T. Gordon.
1959. *A precommercial thinning in ponderosa and Jeffrey pine.* J. For. 57(12):900-904, illus.
Thinning to a spacing of 9 feet by 9 feet with portable brush cutter power saws cost about 10 cents per released tree.

218. Teeguarden, Dennis E., and Donald T. Gordon.
1964. *Thinning increases growth of stagnated ponderosa and Jeffrey pine sapling stands.* J. For. 62(2):114.
At Blacks Mountain Experimental Forest, thinned trees, after 5 years' growth, grew three times as fast in diameter and 67 percent faster in height than comparable trees on a control area.

219. Tevis, L., Jr.
1956. *Pocket gophers and seedlings of red fir.* Ecology 37(2):379-381.
Overgrazing, pocket gopher activity, and a bumper crop of red fir seed worked together and allowed red fir to invade a turf of Idaho fescue.

220. Wagener, Willis W.
1955. *Preliminary guidelines for estimating the survival of firedamaged trees.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 98, 9 p. Berkeley, Calif.
Outlines general principles influencing the survival of trees and suggests how these may be applied in marking timber for salvage following fire.

221. Wagener, Willis W.
1961. *Guidelines for estimating the survival of fire-damaged trees in California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 60, 11 p. Berkeley, Calif.
Provides guides, by tree species or species groups, for judging survival chances of individual trees, with survival depending upon season when the fire occurred, pre-fire growth vigor of the tree, and degree of damage to cambium, foliage and twigs.

222. Wagener, Willis W.
1970. *Frost cracks . . . a common defect in white fir in California.* USDA Forest Serv. Res. Note PSW-209, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Percent of trees with frost cracks increased as tree diameter increment increased on the east slope, but decreased on the west slope.

223. Walters, Gerald A.
1969. *Direct seeding of brushbox, lemon-gum eucalyptus, and cluster pine in Hawaii.* USDA Forest Serv. Res. Note PSW-199, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
After 1 year only two brushbox seed spots were stocked, lemon-gum eucalyptus had significantly more seed spots stocked in mulched plots, and cluster pine had significantly less.

224. Walters, Gerald A., and Thomas H. Schubert.
1969. *Saligna eucalyptus growth in a five-year-old spacing study in Hawaii.* J. For. 67(4):232-234, illus.
In 5 years, trees in all spacings averaged over 72 feet in height, dominant and codominant trees averaged over 85 feet.

225. Walters, Gerald A.
1970. *Bare-root and balled-root planting stock of saligna eucalyptus . . . differ in survival, early growth.* Tree Planters' Notes 21(2):14-16.
Balled-root seedling survival was significantly greater than bare-root seedling survival at all three sites on Maui, Hawaii.

226. Walters, Gerald A.
1970. *Direct seeding of lemon-gum eucalyptus, redwood, and brushbox in Hawaii.* USDA Forest Serv. Res. Note PSW-212, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Lemon-gum eucalyptus had fair stocking and height growth after 1 year, but redwood and brushbox had poor stocking and height growth.

227. Walters, Gerald A.
1970. *Selecting timber species to replace killed firetree in Hawaii.* USDA Forest Serv. Res. Note PSW-211, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif.
Among seven species underplanted, Australian toon was the most satisfactory of the species tested for reforesting.

228. Walters, Gerald A., and Craig D. Whitesell.
1971. *Direct seeding trials of three major timber species in Hawaii.* USDA Forest Serv. Res. Note PSW-234, 2 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
After 1 year all species made rapid height growth, with good stocking for West Indies mahogany and monkey-pod and poor stocking for lemon-gum eucalyptus.

229. Walters, Gerald A.
1971. *A species that grew too fast—Albizia falcataria.* J. For. 69(3):168, illus.
In 2 years *Albizia falcataria* averaged 30 feet tall and 5 inches d.b.h. and were shading out adjacent species.

230. Walters, Gerald A.
1971. *Survival and growth of saligna eucalyptus seedlings treated with a transpiration retardant in Hawaii.* Tree Planters' Notes 22(1):2-4.
After 1 year, survival of seedlings dipped in retardant was significantly greater than that of control seedlings on dry sites.

231. Walters, Gerald A.
1972. *Chemical treatment of bare-root saligna eucalyptus seedlings offers no advantages.* Tree Planters' Notes 23(4):4-7.
Transpiration retardant All-Safe and the root stimulant Nu-Gro offered no advantages over bare-root control seedlings.

232. Walters, Gerald A.
1972. *Coppicing to convert small cull trees to growing stock.* USDA Forest Serv. Res. Note PSW-272, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Australian toon and tropical ash showed the greatest conversion potential, hoop-pine and Moreton-bay-chestnut showed intermediate potential, and Queensland-maple showed little potential.

233. Walters, Gerald A.
1972. *Packing methods studied for Australian toon and slash pine plantings.* Tree Planters' Notes 23(4)7-9.
Packing in sphagnum moss and plastic resulted in the same survival rate as did packing in Kraft-polyethylene bags.

234. Walters, Gerald A.
1972. *Survival of tropical ash planted in Tordon-treated soils in Hawaii.* USDA Forest Serv. Res. Note PSW-263, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Seedlings had 80 percent survival 5 to 9 weeks after summer and winter applications of 5, 10, and 15 pounds active ingredients per acre on two sites.

235. Walters, Gerald A., and Herbert L. Wick.
1973. *Coppicing to convert cull Australian toon, tropical ash to acceptable trees.* USDA Forest Serv. Res. Note PSW-283, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes an exploratory trial of trying to improve stands of Australian toon and tropical ash by coppicing.

236. Walters, Gerald A.
1973. *Growth of saligna eucalyptus, a spacing study after ten years.* J. For. 71(6):346-348, illus.
After 10 years the wider spacings being tried appear to be the best for growing saligna eucalyptus sawtimber in Hawaii.

237. Walters, Gerald A.
1974. *Araucaria* (Jussieu). Araucaria. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 223-225, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

238. Walters, Gerald A.
1974. *Cryptomeria Japonica* (L.F.) Don. Cryptomeria. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 361-362, illus.
See item 237 above.

239. Walters, Gerald A., F. T. Bonner, and E. Q. P. Petteys.
1974. *Pithecellobium* Mart. Blackbead. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 639-640, illus.
See item 237 above.

240. Walters, Gerald A.
1974. *Polystyrene bullets not satisfactory for reforestation in Hawaii.* Tree Planters' Notes 25(2):22-23, illus.
In a test with *Eucalyptus saligna* and *Acacia koa* seedlings, problems were encountered in loading the polystyrene bullets with planting medium and in planting the seedling bullets in the field.

241. Walters, Gerald A.
1974. *Seedling containers for reforestation in Hawaii.* Proc. North Am. Containerized Forest Tree Seedling Symp., Denver, Colo., Aug. 26-29, 1974. Great Plains Agric. Council Publ. 68:336-338.
The Walters' bullet system proved unsatisfactory for reforestation in Hawaii, but the styroblock system proved satisfactory for four tropical hardwood species tested on four different soils.

242. Walters, Gerald A.
1974. *Styroblocks: new technique for raising and planting seedlings in Hawaii.* Tree Planters' Notes 25(4):16-18.
The technique of growing and transporting seedlings in modular containers called styroblocks appears to have considerable potential for improving field planting in Hawaii's reforestation program.

243. Walters, Gerald A.
1974. *Toona australis* Harms. Australian toon. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 813-814, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

244. Walters, Gerald A.
1975. *Slow-release fertilizer aids early growth of Australian toon and Queensland-maple in Hawaii.* Tree Planters' Notes 26(3):12-13, 30.
Fertilizing Australian toon and Queensland-maple seedlings with Osmocote, a slow release fertilizer, is a promising method of increasing height growth and thus reducing weeding requirements.

245. Wear, John F., and Benton Howard.
1966. *New tree marking system improves forest spraying operations.* 8 p., illus. U.S. Forest Serv. Pacific Northwest Region, Portland, Oreg.
Finds that the application of either a highly reflective paint or a weighted streamer to the top of a dominant tree results in a boundary marker or spray plot marker that a pilot can see for about a mile or more, terrain permitting.

246. Wear, John F., and Robert G. Winterfeld.
1966. *Sampling tree tops by helicopter . . . special pole pruner cuts branchlets.* U.S. Forest Serv. Res. Note PSW-131, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a new technique for sampling tops of tall Douglas-fir trees by using a special pole pruner that cuts and holds a branchlet.

247. Weidman, R. H.
1943. *Watering plantation trees.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 31, 3 p. Berkeley, Calif.
The distribution and amount of rainfall during the first growing season and the water-holding capacity of the soil determine whether plantation trees need watering to assure survival.

248. Weidman, R. H., and C. R. Berriman.
1944. *Watering plantation trees.* J. For. 42(6):435-437.
Highly satisfactory survival was obtained by watering during the first summer only in a part of California where the total rainfall for June, July, and August is only ¾ inch.

249. Whitesell, Craig D., and Max F. Landgraf.
1966. *Growing Queensland-maple on lava rocklands in Hawaii.* U.S. Forest Serv. Tree Planters' Notes 77:1-3.
Queensland-maple, a high quality hardwood species native to Australia, could be an important addition to the State's reforestation program.

250. Whitesell, Craig D., and Bruce J. Rogers.
1966. *Queensland-maple seedlings in Hawaii . . . growth accelerated after first year.* U.S. Forest Serv. Res. Note PSW-127, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Seedlings planted on lava rockland grew slowly in the first year after which growth rates accelerated for the next 3 years.

251. Whitesell, Craig D.
1970. *Early effects of spacing on loblolly pine in Hawaii.* USDA Forest Serv. Res. Note PSW-223, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
At age 7, loblolly pine seedlings averaged 30 feet tall in all spacings, and had a 95 percent survival rate.

252. Whitesell. Craig D., and Myron O. Isherwood, Jr.
1971. *Adaptability of 14 tree species to two hydrol-humic latosol-soils in Hawaii.* USDA Forest Serv. Res. Note PSW-236, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
No one species proved outstanding, but several showed characteristics which could be used to develop productive forests of mixed species.

253. Whitesell, Craig D., Herbert L. Wick, and Nobuo Honda.
1971. *Growth-response of a thinned tropical ash stand in Hawaii...after 5 years.* USDA Forest Serv. Res. Note PSW-227, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Net basal area growth during a 5-year period averaged 4.2 sq. ft./acre/yr. on 162 trees, compared to 2.8 sq. ft./acre/yr. on 342 trees in an unthinned control.

254. Whitesell, Craig D.
1974. *Acacia* Mill. Acacia. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 184-186, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

255. Whitesell, Craig D.
1974. *Effects of spacing on loblolly pine in Hawaii after 11 years.* USDA Forest Serv. Res. Note PSW-295, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports survival, diameter, basal area, height, and crown development of 11-year-old *Pinus taeda* planted at 6-, 8-, 10-, and 12-foot spacings on the island of Maui.

256. Whitesell, Craig D.
1974. *Lucaena Leucocephala* (Lam.) de Wit. Leadtree. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 491-493, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

257. Whitesell, Craig D.
1974. *Planting trials of 10 Mexican pine species in Hawaii.* USDA Forest Serv. Res. Paper PSW-103, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Initial survival was poor, subsequent mortality was low, growth and vigor were satisfactory, and average annual height growth ranged from 1 to 3 feet.

258. Whitesell, Craig D.
1975. *Growth of young saligna eucalyptus in Hawaii, 6 years after thinning.* USDA Forest Serv. Res. Note PSW-299, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
No significant differences in growth response were found among light, medium, and heavy thinning treatments tested.

259. Wick, Herbert L., and Craig D. Whitesell.
1969. *Stump diameter affects sprout development of tropical ash.* USDA Forest Serv. Res. Note PSW-196, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Larger parent trees produced larger, faster-growing

sprouts than did smaller parent trees, 70 percent of the stumps produced at least one sprout of acceptable form and of average or better vigor.

260. Wick, Herbert L., and Robert E. Burgan.
1970. *A spacing trial in Australian toon . . . an interim report.* USDA Forest Serv. Res. Note PSW-220, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Spacing interval did not affect diameter or height growth; basal area per acre decreased with an increase in spacing; and survival was not affected by spacing interval.

261. Wick, Herbert L., Robert E. Nelson, and Libert K. Landgraf.
1971. *Australian toon planted in Hawaii: tree quality, growth, and stocking.* USDA Forest Serv. Res. Paper PSW-69, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Good survival and growth rates and good quality were found on areas with deep soil, good drainage, and aa or broken pahoehoe rock.

262. Wick, Herbert L., and Gerald A. Walters
1974. *Albizia* Durazz. Albizzia. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 203-205, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

263. Wick, Herbert L.
1974. *Flindersia brayleyana* F. Muell. Queensland-maple. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 409-410, illus.
See item 262 above.

264. Wilm, H. G.
1936. *The relation of successional development to the silviculture of forest burn communities in southern New York.* Ecology 17(2):283-291.
Investigates the trends of succession in existing secondary communities and suggests possible modes of treatment that can be applied to a community in order to hasten or alter its development.

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265. Berg, Arthur R., and E. G. Cutter.
1969. *Leaf initiation rates and volume growth rates in the shoot apex of chrysanthemum.* Am. J. Bot. 56(2):153-159, illus.
Defoliation by periodic removal of leaves larger than 1 cm caused a statistically significant increase in initiation rate, but not as high a rate as that of the first 10 days of bud growth.

266. Berg, Arthur R.
1970. *Relation of plastochron to anatomy and growth in the shoot apex of chrysanthemum.* Am. J. Bot. 57(1):24-32, illus.
Apices showed no differences as to regularity of cell pattern, presence of cambium-like zone, and appearance of the second tunica layer or staining pattern.

267. Berg, Arthur R., and Timothy R. Plumb.
1972. *Bud activation for regrowth.* In *Wildland shrubs—their biology and utilization.* USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 279-286. Intermt. Forest and Range Exp. Stn., Ogden, Utah.
Reviews reports on the development, dormancy, and activation of meristematic structures in annual shrub plants.

268. Berg, Arthur R.
1974. *Arctostaphylos* Adans. Manzanita. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 228-231, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

269. Boe, Kenneth N.
1974. *Sequoia sempervirens* (D. Don) Endl. Redwood. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 764-766, illus.
See item 268 above.

270. Boe, Kenneth N.
1974. *Sequoiadendron giganteum* (Lindl.) Buchholz. Giant Sequoia. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 767-768, illus.
See item 268 above.

271. Bryan, L. W., and Clyde M. Walker.
1962. *A provisional check list of some common native and introduced forest plants in Hawaii.* U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 69, 36 p. Berkeley, Calif.
Lists scientific and common names for more than 150 genera of trees and several shrubs, ferns, and vines.

272. Buttery, R. F., and L. R. Green.
1958. *Checklist of plants of the San Joaquin Experimental Range.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 23, 32 p. Berkeley, Calif.
Lists abundance and habitat descriptions for each species growing on this central Sierra foothill laboratory.

273. Crafts, A. S., and Carl E. Crisp.
1971. *Phloem transport in plants.* 481 p. illus., W. H. Freeman, San Francisco.
Discusses structure-function relationships in phloem transport and reports recent experiments on the mechanism of translocation.

274. Critchfield, William B., and G. L. Allenbaugh.
1965. *Washoe pine on the Bald Mountain Range, California.* Madroño 18:63-64.
Reports a new locality of occurrence 20 and 90 miles from the two previously reported stands.

275. Critchfield, William B., and Elbert L. Little, Jr.
1966. *The geographic distribution of the pines of the world.* U.S. Dep. Agric. Misc. Publ. 991, 97 p., illus.
Information concerning the natural distribution of the genus *Pinus* is summarized in the form of maps.

276. Critchfield, William B.
1966. *A new conifer herbarium.* Taxon 15(6):217-218.
A herbarium restricted mostly to *Pinus* and *Abies* has been set up at the Institute of Forest Genetics, Placerville, California, which includes a reference collection of pines and firs.

277. Critchfield, William B., and Gordon L. Allenbaugh.
1969. *The distribution of Pinaceae in and near northern Nevada.* Madroño 20(1):12-26, illus.
Summarizes available information about the distribution in and near the northern Great Basin region.

278. Critchfield, William B.
1970. *Shoot growth and leaf dimorphism in Boston ivy (Parthenocissus tricuspidata).* Am. J. Bot. 57(5):535-542.
Compares similarities and differences between Boston ivy and other woody plants that show heterophylly in which leaf dimorphism is related to shoot growth.

279. Critchfield, William B.
1971. *Profiles of California vegetation.* USDA Forest Serv. Res. Paper PSW-76, 54 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The 57 elevational profiles assembled illustrate the dominant vegetation of the Sierra Nevada and the Coast Range as it existed in the 1930's.

280. Critchfield, William B.
1971. *Shoot growth and heterophylly in Acer.* A. Arnold Arbor. 52(2):240-266, illus.
Describes shoot growth in red and striped maple, patterns of shoot growth and heterophylly in other members of the genus, and compares to other groups with similar patterns.

281. Duffield, John W., and W. C. Cumming.
1949. *Does Pinus ponderosa occur in Baja California?* Madroño 10(1):22-24.
An effort to collect seed and botanical specimens was unsuccessful, all yellow pines were clearly *Pinus jeffreyi.*

282. Duffield, John W.
1949. *The pines of the Eddy Arboretum.* Arbor. Bull. 12(4):17-20.
Describes the climate, location and layout of the Eddy Arboretum and gives detailed descriptions of various pines growing there.

283. Dunning, Duncan.
1946. *Roots of forest trees.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 52, 42 p. Berkeley, Calif.
Presents an extensive bibliography of publications on roots and root systems.

284. Echols, Robert M.
1969. *Permanent slices of stained wood fibers without dehydration or cover glasses.* Forest Sci. 15(4):411.
Describes the preparation of permanent slides of stained wood fibers with polyvinyl acetate.

285. Echols, Robert M., and M. T. Conkle.
1971. *The influence of plantation and seed-source elevation on wood specific gravity of 29-year-old ponderosa pines.* Forest Sci. 17(3):388-394, illus.
Genetic, environmental, and age effects were found in 29-year-old ponderosa pine progeny from different elevational sources, when they were grown at altitudes of 960, 2730, and 5650 ft.

286. Echols, Robert M.
1972. *Patterns of wood density distribution and growth rate in ponderosa pine.* Proc. Symp. on the Effect of Growth Acceleration of Properties of Wood, Madison, Wis. 1971:H1-H16, illus.
Unthinned trees decreased in growth rate, but increased in wood density, thinning increased growth rate, trees released but not fertilized decreased in wood density.

287. Echols, Robert M.
1973. *Effects of elevation and seed source on tracheid length in young ponderosa pine.* For. Sci. 19(1):46-49, illus.
Regardless of elevation of parent source, a high-elevation planting on the westside Sierra Nevada will produce trees with larger diameters and shorter tracheids than planting at a lower elevation.

288. Echols, Robert M.
1973. *Uniformity of wood density assessed from X-rays of increment core.* Wood Sci. and Tech. 7(1):34-44, illus.
Reports variations on density within and across growth rings measured in lodgepole pine, ponderosa pine, and Douglas-fir samples by using X-rays and a digital integrator.

289. Evans, Lance S., and Arthur R. Berg.
1971. *Leaf and apical growth characteristics in triticum.* Am. J. Bot. 58(6):540-543, illus.
Leaf initiation rate, leaf primordium growth rates, and apical volume growth rates were determined for seedlings of *Triticum aestivum* cv. ramona 50 under controlled environmental conditions.

290. Evans, Lance S., and Arthur R. Berg.
1972. *Qualitative histochemistry of the shoot apex of Triticum.* Can. J. Bot. 50(1):241-244, illus.
The shoot apex of *Triticum aestivum* cv. ramona 50 was studied histologically to describe cell lineages and the events during the initiation of the fifth leaf.

291. Foote, P. A., and N. T. Mirov.
1933. *A phytochemical investigation of the oleoresin of Pinus monticola* Dougl. J. Am. Pharm. Assoc. 22(9):825-834.
Details of the extraction are given supplemented by tables of yield for oleoresin, oil and rosin, the oil contains 60 percent D-α-pinene, 26 percent β-pinene, 1-2 percent N-undecane and sesquiterpenes.

292. Fowells, Harry A.
1941. *The period of seasonal growth of ponderosa pine and associated species.* J. For. 39(7):601-608.
A comparison of the seasonal height and radial growth of ponderosa pine and six other conifers reveals significant differences in time of start of growth and length of growing period.

293. Fowells, Harry A.
1950. *Some observations on the seedfall of sugar pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 71, 3 p. Berkeley, Calif.
Reports data on the radius at which natural seeding occurs, and the effect of wind on seedfall.

294. Fowells, Harry A., and Gilbert H. Schubert.
1956. *Silvical characteristics of sugar pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn Tech. Paper 14, 19 p., illus. Berkeley, Calif.
Includes a description of the species, its habitat conditions, and growth habits.

295. Fowells, Harry A., and N. B. Stark.
1966. *Natural regeneration in relation to environment in the mixed conifer forest type of California.* U.S. Forest Serv. Res. Paper PSW-24, 14 p. illus Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif.
The germination, survival, and growth of ponderosa pine, sugar pine, white fir, and incense-cedar were studied in relation to environmental factors in the central Sierra Nevada, California.

296. Gause, Gerald W.
1966. *Silvical characteristics of bigcone Douglas-fir (Pseudotsuga macrocarpa* [Vasey] Mayr). U.S. Forest Serv. Res. Paper PSW-39, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes habitat conditions and life history.

297. Gifford, Ernest M.,and N. T. Mirov.
1960. *Initiation and ontogeny of the ovulate strobilus in ponderosa pine.* Forest Sci. 6(1):19-25, illus.
Initiation occurred during the first weeks of September, with strobili growth continuing throughout the late fall and winter while vegetative shoots entered a rest period.

298. Griffin, James R.
1964. *Cone morphology in Pinus sabiniana.* J. Arnold Arbor. 45(2):260-273, illus.
Results of samples taken throughout the natural range in California showed that cone scale morphology was quite stable within trees but so variable within populations that population differences were often inconclusive.

299. Griffin, James R.
1964. *David Douglas and the Digger pine, some questions.* Madroño 17(7):228-230, illus.
The circumstances of the discovery of *Pinus sabiniana* by David Douglas in 1831 are reviewed, and evidence is offered to refute Douglas' claim that he collected the species in the Umpqua region of Oregon.

300. Griffin, James R.
1964. *Isolated Pinus ponderosa forests on sandy soils near Santa Cruz.* Ecology 45(2):410-412.
Several unique floristic and edaphic characteristics of these isolated pine forests are described.

301. Griffin, James R.
1964. *A new Douglas-fir locality in southern California.* Forest Sci. 10(3):317-319, illus.
Describes a small, disjunct *Pseudotsuga menziesii* stand within the *Pinus muricata* forest on the Purisima Hills in Santa Barbara County, which is 90 miles southeast of the previously reported southern limit of the species within California.

302. Griffin, James R.
1966. *Notes on disjunct foothill species near Burney, California.* Leafl. of West. Bot. 10(15):296-298.
The distribution and ecological relationships of foothill species *(Quercus douglasii, Pinus sabiniana, Rhus diversiloba)* in this montane area are briefly outlined.

303. Griffin, James R., and C. O. Stone.
1967. *MacNab cypress in northern California—a geographic review.* Madroño 19(1):19-27, illus.
Six previously unreported and two other little known stands in Shasta and Tehama Counties are described.

304. Griffin, James R.
1967. *Soil moisture and vegetation pattern in northern California forests.* U.S. Forest Serv. Res. Paper PSW-46, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Soil moisture patterns during the growing season are outlined along with moisture tension characteristics of samples taken from 29 soil-vegetation plots in the pine and mixed conifer forests of Shasta County.

305. Griffin, James R., and William B. Critchfield.
1972. *The distribution of forest trees in California.* USDA Forest Serv. Res. Paper PSW-82, 114 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The distribution of 85 forest and woodland tree species is illustrated on maps, supplemented by notes on the ecological and taxonomic context of each species.

306. Griffin, James R.
1975. *Plants of the highest Santa Lucia and Diablo Range peaks, California.* USDA Forest Serv. Res. Paper PSW-110, 50 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes the life form, plant community preferences, ecological features, and taxonomic problems of vascular plants found on six of the highest ridges in the south Coast Ranges.

307. Hallin, William E.
1957. *Silvical characteristics of California red fir and Shasta red fir.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 16, 18 p., illus. Berkeley, Calif.
Summarizes silvical information on California red fir and Shasta red fir—two species considered to be almost identical in their silvical characteristics except for cone structure.

308. Hallin, William E.
1957. *Silvical characteristics of Jeffrey pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 17, 11 p., illus., Berkeley, Calif.
Includes a description of the species, its habitat conditions, growth habits, hybrids, and distribution.

309. Hellmers, Henry, and L. Machlis.
1956. *Exogenous substrate utilization and fermentation by the pollen of Pinus ponderosa.* Plant Physiol. 31(4):284-289.
Presents data on food reserves, their rate of use during germination, and the effect of various metabolic inhibitors.

310. Hellmers, Henry.
1957. *Chaparral plants.* In *Environmental control of plant growth,* Chapter 14. F. W. Went, ed. Chronica Botanica.
Describes the testing of herbaceous plants for use as quick cover on burned areas and the testing of introduced woody plants for use in erosion control in southern California.

311. Hellmers, Henry, and William E. Sundahl.
1959. *Response of Sequoia sempervirens* (D. Don) Endl. *and Pseudotsuga menziesii* (Mirb.) Franco *seedlings to temperature.* Nature 184(4694):1247-1248.
Redwood and Douglas-fir seedlings responded differently in growth to a series of combinations of day-night temperatures.

312. Hellmers, Henry, and James Bonner.
1960. *Photosynthetic limits of forest tree yields.* Soc. Am. For. Proc. 1959:32-35.
Analysis of available data showed that beech trees, during the period of leaf retention, and Scots pine, over a 12-month period in an ice-free climate, were 2 ± 0.5 percent efficient in converting sunlight to plant material, an efficiency that is within the range of crop plants.

313. Hellmers, Henry.
1962. *Physiological changes in stored pine seedlings.* Tree Planters' Notes 53:9-10, illus.
A decrease in vigor in stored seedlings could be detected by a decrease in the starch present in the plants during storage.

314. Hellmers, Henry.
1962. *Temperature effect on optimal tree growth.* In

Tree growth. p. 275-297. T. T. Kozlowski, ed. Ronald Press, New York.
The different responses to temperature of various coniferous species may be primarily to day temperature or total heat over a 24-hour period.

315. Hellmers, Henry.
1963. *Effects of soil and air temperatures on growth of redwood seedlings.* Bot. Gaz. 124:172-177, illus.
High temperature stimulated top growth, and cool air combined with warm soil favored root growth, although response depended to some extent upon seedling size and age.

316. Hellmers, Henry.
1963. *The formation of wood in forest trees. Distribution of growth in tree seedling stems as affected by temperature and light.* Second Int. Cabot Symp. Proc. 1963:533-547.
A temperature-light intensity interaction exists, and a photo-period-light intensity interaction affects the distribution of growth in coniferous seedlings with age of seedlings also affecting the distribution of growth.

317. Hellmers, Henry.
1963. *Some temperature and light effects in the growth of Jeffrey pine seedlings.* Forest Sci. 9:189-201, illus.
Total daily degree-hours appeared to be the dominant temperature measure in determining the maximum dry-weight production.

318. Hellmers, Henry.
1964. *An evaluation of the photosynthetic efficiency of forests.* Q. Rev. Biol. 39(3):249-257.
Reviews available data and suggests that a stand of trees has a relatively high photosynthetic efficiency in comparison to that of an agricultural crop.

319. Hellmers, Henry.
1966. *Growth response of redwood seedlings to thermoperiodism.* Forest Sci. 12(3):276-283, illus.
Seedlings exhibited optimal growth under controlled conditions of 19° C. day temperature and 15° C. night temperature, with 8 hours of natural light and 8 hours of low-intensity artificial light.

320. Hellmers, Henry.
1966. *Temperature action and interaction in the growth of red fir seedlings.* Forest Sci. 12(1):90-96, illus.
Finds that the day-night temperature relationship affected height, stem basal area at ground level, and branch growth with the different growth patterns under different temperatures accounting for the tallest group of plants not being the heaviest.

321. Hellmers, Henry, and Richard P. Pharis.
1968. *Influence of photoperiod and photoperiodic cycles on the growth of coastal redwood seedlings.* Bot. Gaz. 129(1):53-57, illus.
Finds that the plants used light energy for height growth and dry matter production most efficiently when grown under a 20-hour photoperiod on a 24-hour cycle.

322. Hellmers, Henry, M. K. Genthe, and F. Ronco.
1970. *Temperature affects growth and development of Engelmann spruce.* Forest Sci. 16(4):447-452, illus.
Night temperature was the most important factor in increasing all phases of growth except bud development.

323. Hormay, August L.
1942. *A key for identifying some important annual range grasses in the immature stage.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 26, 12 p. Berkeley, Calif.
Presents a simple key with descriptions of size, stature, hairiness, and illustrations of the ligules for identifying annual grasses in their early stages of growth.

324. Jespersen, B. S.
1942. *The genus Chrysothamnus in California and western Nevada.* U.S. Forest Serv. Calif. Forest and Range Exp Stn. Res. Note 27, 19 p. Berkeley, Calif.
Gives chart descriptions and distribution maps of the species *chrysonthamnus* and its varieties.

325. Johnson, Leroy C., and Sister M. Frieda Ward.
1972. *Male cone production in Metasequoia glyptostroboides growing at the Dominican College of San Rafael, California.* Calif. Hortic. J. 33(3):98-100, 119, illus.
Male cones of two dawn redwoods are produced in leaf axils on highly specialized foliar branches and not on inflorescences as previously reported.

326. Johnson, Leroy C.
1974. *Cupressus* L. Cypress. In *Seeds of the woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p 363-369, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

327. Johnson, Leroy C.
1974. *Metasequoia glyptostroboides* Hu and Cheng. Dawn redwood. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 540-542, illus.
See item 326 above.

328. Kotok, E. I.
1933. *Fire, a major ecological factor in the pine region*

of California. Proc. Fifth Pacific Sci. Congr. Victoria and Vancouver, B. C., 1933:4017-4022.
Briefly considers the silvical characteristics of the forest and its response to fire and describes how fires directly and indirectly affect the biotic forest community.

329. Kraebel, Charles J., and F. H. Schumacher.
1937. *Notes on collecting and handling seeds of native California plants.* 2 p. U.S. Forest Serv. Calif.Forest and Range Exp. Stn., Berkeley, Calif.
Discusses some of the procedures and precautions which have proved to be of value for collecting work on the National Forests.

330. Krugman, Stanley L.
1967. *A gibberellin-like substance in the immature pine seed.* Forest Sci. 13(1):29-37, illus.
A gibberellin-like substance was found to be different from at least two of the chemically known gibberellins isolated from angiosperm seeds and fruits.

331. Krugman, Stanley L., and William B. Critchfield.
1968. *Red pine needle structure.* Nature 217(5129):685-686, illus.
To correct a published misinterpretation of red pine needle structure, the anatomy of immature seedling needles was reinvestigated.

332. Krugman, Stanley L., and Julia F. Littlefield.
1968. *A useful single-solution polychrome stain for plant material . . . Brook Cyte-Chrome I.* U.S. Forest Serv. Res. Note PSW-170, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Staining time using this polychrome stain averaged only 10 minutes, and exact timing of staining and destaining was not as critical as with most of the commonly used stains.

333. Krugman, Stanley L., and James L. Jenkinson.
1974. *Pinus* L. Pine. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 598-638, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

334. Krugman, Stanley L., William I. Stein, and Daniel M. Schmitt.
1974. *Seed biology.* In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 5-40, illus.
A knowledge of the life processes—initiation, development, ripening, dispersal, dormancy, and germination—is basic for success in harvesting and using seeds.

335. Lanner, Ronald M.
1963. *Growth and cone production of knobcone pine under interrupted nights.* U.S. Forest Serv. Res. Note PSW-38, 16 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Treatments which consisted of an illumination at midnight for 1 hour over various seasonal periods of time had no effect on the number of trees flowering during the next year, on height growth or its seasonal distribution, or on frequency of summer shoots.

336. Lanner, Ronald M.
1964. *Adventitious rooting—a response to Hawaii's humid environment.* U.S. Forest Serv. Res. Note PSW-54, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Adventitious roots on trunks or limbs of eight species of introduced forest trees in Hawaii had no adaptations against drying out, and could survive only under conditions of extreme humidity.

337. Lanner, Ronald M.
1964. *Clones of Nepal alder in Hawaii.* J. For. 62(9):636-637.
Clones of Nepal alder in the Kohala Mountains are the result of windthrown trees rooted on one side putting out epicormic shoots, which in turn often put out adventitious roots.

338. Lanner, Ronald M.
1964. *Temperature and the diurnal rhythm of height growth in pines.* J. For. 62(7):493-495.
Evidence suggests that diurnal rhythms of pine shoot growth are temperature-induced, rather than under the control of the light-dark cycle.

339. Lanner, Ronald M.
1965. *Modifications in the growth habit of exotic trees in Hawaii.* Soc. Am. For. Proc. 1965:36-37.
Several species show drastically modified growth habits such as producing adventitious roots.

340. Lanner, Ronald M.
1966. *Adventitious roots of Eucalyptus robusta in Hawaii.* Pac. Sci. 20(3):379-381.
Suggests that the occurrence of adventitious roots within the bark of standing trees is related to the moisture content of the bark.

341. Lanner, Ronald M.
1966. *Needed: A new approach to pollen dispersion.* Silvae Genetica 15(2):50-52, illus.
Suggests that thermal shell activity is a mechanism that

can account for high pollen densities at moderate distances, and that mass precipitation of pollen can be effected by rain.

342. Lanner, Ronald M.
1966. *The phenology and growth habits of pines in Hawaii.* U.S. Forest Serv. Res. Paper PSW-29, 25 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports on studies intended to aid in defining in terms of the interaction between the species and its new environment.

343. Lanner, Ronald M.
1966. *Phenology of Acacia koa on Mauna Loa, Hawaii.* U.S. Forest Serv. Res. Note PSW-89, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Flowering was strongly seasonal, varying in length of season according to elevation.

344. Lanner, Ronald M.
1966. *An unusual bisexual Agathis cone.* Pac. Sci. 20(3):382-383.
Reports finding a bisexual cone of Queensland kauri with a female base and a male tip, in Hilo, Hawaii.

345. Liddicoet, A. R., and F. I. Righter.
1960. *Trees of the Eddy Arboretum.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 43, 41 p., illus. Berkeley, Calif.
Scientific and common names, notes on natural distribution, and dates of flowering are tabulated for all species and hybrids of pines.

346. Lindquist, J. L.
1974. *Redwood . . . an American wood.* U.S. Dep. Agric. FS-262, 8 p., illus.
Summarizes distribution, growth, production, uses, and characteristics.

347. Little, Elbert L., Jr., and William B. Critchfield.
1969. *Subdivisions of the genus Pinus (pines).* U.S. Dep. Agric. Misc. Publ. 1144, 51 p., illus.
Summarizes nomenclature and includes 22 distribution maps as a supplement to U.S. Dep. Agric. Misc. Publ. 991 (1966).

348. Magill, Arthur W.
1974. *Chamaebatia foliolosa* Benth. Bearmat. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 315, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

349. Magill, Arthur W.
1974. *Chilopsis linearis* (Cav.) Sweet. Desertwillow. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p 321-322, illus.
See item 348 above.

350. Magill, Arthur W.
1974. *Photinia arburifolia* Lindl. Christmasberry. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 582-583, illus.
See item 348 above.

351. Marion, Lois.
1943. *The distribution of Adenostoma sparsifolium.* Am. Midl. Nat. 29(1):106-116.
Presents the geographic boundaries of distribution, records of altitude and slope exposure, and lists associated species.

352. Mason, Herbert L., and W. Palmer Stockwell.
1945. *A new pine from Mount Rose, Nevada.* Madroño 8(2):61-63.
An unusual pine similar to *Pinus jeffreyi* but with important differences in structure, biochemistry, and behavior is given the name *Pinus washoensis.*

353. Maul, D. C.
1958. *Silvical characteristics of white fir.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 25, 22 p.
Outlines the distribution, life history, and growth of this important western tree.

354. May, R. H., and G. E. Sindel.
1955. *The northern outpost of the giant sequoia.* Sierra Club Bull. 40(8):70-72.
Locates and describes the most northerly grove of *Sequoia gigantea.*

355. McDonald, Philip M., and William Sundahl.
1966. *Pacific madrone . . . a general bibliography for a promising species.* U.S. Forest Serv. Res. Note PSW-98, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Presents 56 references, of which 19 emphasize the desirable wood working characteristics of the species.

356. McDonald, Philip M., and W. E. Sundahl.
1967. *California black oak . . . a general bibliography on an increasingly valuable species.* U.S. Forest Serv. Res. Note PSW-134, 7 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Lists 97 references which include most of the available citations on the species with major emphasis on injurious agents, wood strength, and seasoning characteristics.

357. McDonald, Philip M.
1969. *Silvical characteristics of California black oak (Quercus kelloggii* Newb.). USDA Forest Serv. Res. Paper PSW-53, 20 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes the climatic, edaphic, physiographic, and biotic habitat conditions of the natural range of California black oak and how this tree reproduces, grows, and dies.

358. Mirov, N. T.
1929. *Distribution of vegetation of Olhon Island, Lake Baikal, eastern Siberia.* Ecology 10(3):351-353.
Five forest associations in the northeast and two prairie associations in the southwest and north have been recognized, with *Pinus silvestris* being the predominant species.

359. Mirov, N. T.
1936. *Germination behavior of some California plants.* Ecology 17(4):667-672.
Concludes that there is no consistent relation between the systematic position of a plant and its germination behavior.

360. Mirov, N. T.
1937. *Certain phases of enzyme activity in seeds.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 7, 11 p. Berkeley, Calif.
Reviews findings pertaining to the enzyme activity in the hydrolysis and synthesis of fats during ripening and germinating.

361. Mirov, N. T.
1941. *Distribution of growth hormone in shoots of two species of pine.* J. For. 39(5):457-464.
Experiments with *Pinus ponderosa* and *Pinus torreyana* show that growth hormone concentration was always higher in fast-growing than in slow-growing trees, but the highest concentration did not coincide with the region of the most vigorous growth.

362. Mirov, N. T.
1943. *Storage and germination of California cork-oak acorns.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 36, 18 p., Berkeley, Calif.
Results indicate that acorns should be kept in cold storage, that their moisture content should be maintained at a high level, and that immediate germination can be suppressed by naphthal eneacetic acid.

363. Mirov, N. T.
1944. *Possible relation of linolenic acid to the longevity and germination of pine seed.* Nature 154(3902):218-219.
Analyzes the difference in the degradation of the unsaturated acids, especially linolenic acid, in the biological oxidation of Jeffrey pine and sugar pine seeds.

364. Mirov, N. T.
1945. *Effect of the crown on the composition of oleoresin in pines.* J. For. 43(5):345-348.
Concludes, on the basis of experiments in the grafting of *Pinus ponderosa* and *Pinus sabiniana,* that the crown has a distinct influence on the chemical composition of the oleoresin in the trunk.

365. Mirov, N. T.
1949. *A tree is a living thing.* U.S. Dep. Agric. Yearb. 1949:1-10.
Traces the life history of a tree and its vital processes, including seed physiology, growth, wood formation, photosynthesis, reproduction, and death.

366. Mirov, N. T.
1950. *Simmondsia-desert shrub offers new uses, from cover crop to wax.* Chemurg. Dig. 9(7):7,8,9.
Describes the history and future management possibilities of the plant, and the chemical composition, industrial uses and scientific value of the seed oil.

367. Mirov, N. T.
1952. *Mr. Pince's Mexican pine.* Madroño 11(7):270-273.
The first accurate description of the habitat and range of *Pinus pinceana* and the first published picture of this rare Mexican pine in its natural environment are given.

368. Mirov, N. T.
1952. *Simmondsia or jojoba, a problem in economic botany.* Econ. Bot. 6(1):41-47.
Simmondsia is a good source of liquid wax but is difficult to grow under cultivation.

369. Mirov, N. T.
1954. *Lodgepole pine discovered and misnamed.* Madroño 12:156-157.
Discusses discovery and nomenclature of lodgepole pine.

370. Mirov, N. T.
1956. *Photoperiod and flowering of pines.* Forest Sci. 2(4):328-332, illus.
Pines performed not as long-day or short-day plants, but as neutral ones whose flowering is not affected by length of day.

371. Mirov, N. T., and Robert G. Stanley.
1959. *The pine tree.* Annu. Rev. Plant Physiol. 10:223-238.
Reviews recent plant physiological research with pines,

including chemical composition, nutrition, mycorrhiza, photosynthesis, growth, auxin, reproduction, and translocation.

372. Neal, Donald L.
1963. *A pocket herbarium for range men.* J. Range Manage. 16(3):145-146, illus.
A method of mounting plants with self-laminating plastic sheets for field use has been developed.

373. Nord, Eamor C.
1959. *Bitterbrush ecology—some recent findings.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 148, 8 p., illus. Berkeley, Calif.
Describes occurrence of *Purshia tridentata* and *P. Glandulosa* in California and sets forth some of the environmental requirements of each.

374. Nord, Eamor C.
1959. *Ecology of bitterbrush.* Ecol. Soc. Am. Bull. 40(3):72.
Highlights ecological studies on antelope and desert bitterbrush in California during a 2-year period.

375. Nord, Eamor C., and George R. Van Atta.
1960. *Saponin—a seed germination inhibitor.* Forest Sci. 6(4):350-353.
Seed coats and bracts of *Atriplex canescens* Pursh. Nutt. were found to contain about 10 percent of a water-soluble saponin.

376. Nord, Eamor C.
1962. *Was this a prize bitterbrush?* J. Range Manage. 15(2):82-83, illus.
An antelope bitterbrush plant found in northeastern California was 12 feet high with a crown spread of 19⅔ feet.

377. Nord, Eamor C.
1965. *Autecology of bitterbrush in California.* Ecol. Monogr. 35(3):307-334, illus.
Two species—antelope bitterbrush and desert bitterbrush—generally occupy separate ranges and show distinctive morphological and physiological characteristics.

378. Nord, Eamor C., Donald R. Christensen, and A. Perry Plummer.
1969. *Atriplex species (or taxa) that spread by root sprouts, stem layers, and by seed.* Ecology 50(2):324-326.
Gardner's saltbush reproduces abundantly by root sprouts under varying site conditions in the eastern Great Basin, upper Colorado River drainage, and in southern California test plantings.

379. Nord, Eamor C.
1974. *Fremontodendron* Cov. Fremontia. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 417-419, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination,, and nursery practices.

380. Nord, Eamor C., and Andrew T. Leiser.
1974. *Nama lobbii* Gray. Woolly nama. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric Handb. 450, p. 551-552, illus.
See item 379 above.

381. Nord, Eamor C., and Lois E. Gunter.
1974. *Salvia sonomersis* Greene. Creeping Sage. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p 751-753, illus.
See item 379 above.

382. Nord, Eamor C., and Amram Kadish.
1974. *Simmondsia chinensis* (Link) C. K. Schneid. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 774-776, illus.
See item 379 above.

383. Oliver, William W.
1967. *Ponderosa pine can stagnate on a good site.* J. For. 65(11):814-816, illus.
On a good timber-producing site in California's middle Sierra Nevada, two stands showed marked differences, with retarded height growth and crown class differentiation in one stand, and normal growth in the adjacent stand.

384. Olson, David F., Jr., and E. Q. P. Petteys.
1974. *Casuarina* L. Casuarina. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 278-280, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

385. Owston, Peyton W., James L. Smith, and Howard G. Halverson.
1969. *Development of some radioisotope procedures for measuring water movement in trees.* U.S. Atomic Energy Comm. Div. Tech. Inf. TID-25136, 55 p., illus. Washington, D.C.
Most rapid movement of phosphorus-32 injected into lateral roots of lodgepole pine and red fir occurred in spring and summer, but some transport took place in midwinter.

386. Owston, Peyton W., James L. Smith, and Howard G. Halverson.
1970. *Development of some radioisotope procedures for*

measuring water movement in trees. Isot. and Radiat. Tech. 7(4):396-401, illus.

Research is underway in the Sierra Nevada of California to quantify the passage of water through individual trees by means of radioactive tracers.

387. Owston, Peyton W., James L. Smith, and Howard G. Halverson.

1970. *Further development of radioisotope techniques for measuring water movement in large trees.* U.S. Atomic Energy Comm. Div. Tech. Inf. TID-25463, 38 p., illus.

Radioisotope studies in the Sierra Nevada have progressed to the point where first approximations may be made of the volume of water moving through boles of individual trees.

388. Owston, Peyton W., James L. Smith, and Howard G. Halverson.

1972. *Seasonal water movement in tree stems.* Forest Sci. 18(4):266-272, illus.

Daytime rates for lodgepole pine and red fir ranged from 12 to 84 cm/hr in summer; winter rates for red fir averaged 0.4 to 1.4 cm/hr.

389. Patric, James H., and Ted L. Hanes.

1964. *Chaparral succession in a San Gabriel Mountain area of California.* Ecology 45(2):353-360, illus.

Data on chaparral succession were obtained from 20 paired one-hundredth acre plots in stands unburned for 40 and 63 years.

390. Petteys, Edwin Q. P.

1974. *Tristania Conferta* R. Br. Brushbox. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 817-818, illus.

Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

391. Philpot, Charles W.

1965. *Diurnal fluctuation in leaf moisture of ponderosa pine and white leaf manzanita leaves.* U.S. Forest Serv. Res. Note PSW-67, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Leaves sampled for moisture content during three 24-hour periods in summer, showed that diurnal fluctuation was highest at night and at a minimum some time during the day.

392. Quick, Clarence R.

1956. *Viable seeds from the duff and soil of sugar pine forests.* Forest Sci. 2(1):36-42.

Reports the kinds and quantities of viable seeds recovered from 64 duff and soil samples collected under certain timber stands.

393. Quick, Clarence R.

1959. *Ceanothus seeds and seedlings on burns.* Madroño 15(3):79-81.

Shows that large numbers of the seeds of several woody plants common to California's mixed-conifer type remain viable for a long time in the soil and are not destroyed by forest fires.

394. Quick, Clarence R., and Alice S. Quick.

1961. *Germination of ceanothus seeds.* Madroño 16(1):23-30.

Several species tested germinated abundantly after storage for 12 to 14 years.

395. Quick, Clarence R.

1961. *How long can a seed remain alive?* In *Seeds.* Yearb. of Agric. 1961, p. 94-99.

Reports review of literature in which records of viability after long storage of seeds are cited and several outstanding seed-longevity experiments are described.

396. Quick, Clarence R.

1962. *Resurgence of a gooseberry population after fire in mature timber.* J. For. 60(2):100-103, illus.

Summarizes a 10 year record of the regeneration of a population of Sierra Nevada gooseberry on a small burn in mature timber, and shows how population development can be evaluated quantitatively.

397. Quinslard, Donald E., and Donald C. Jones.

1969. *Microdetermination of iron in plant tissue with 4,7-diphenyl-1,10-phenanthroline.* Talanta 16:282-283. North Ireland, Pergamon Press.

The wet digestion procedure is safe, rapid and effective, and avoids the use of perchloric acid; the colorimetric procedure is rapid, effective, and particularly useful when many samples are involved.

398. Ratliff, Raymond D.

1974. *Eriogonum fasciculatum* Benth. California buckwheat. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 382-383, illus.

Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

399. Ratliff, Raymond D.

1974. *Haplopappus parishii* (Greene) Blake. Parish goldenweed. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 445, illus.

See item 398 above.

400. Ratliff, Raymond D.
1974. *Lupinus* L. Lupine. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 520-521, illus.
See item 398 above.

401. Ratliff, Raymond D.
1974. *Short-hair sedge . . . its condition in the high Sierra Nevada of California.* USDA Forest Serv. Res. Note PSW-293, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Evaluates 10 mainland sites and one island site in Sequoia and Kings Canyon National Parks, California, to provide a representative sample of foliar cover and standing crop.

402. Reed, Merton J.
1974. *Ceanothus* L. Ceanothus. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 284-290, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

403. Rice, Raymond M.
1963. *Canary Island pine: A fire-tolerant tree.* J. For. 61:868-869, illus.
Recommends planting in recreational areas in the chaparral zone of the southwest, because this pine will produce epicormic branches after its foliage has been consumed in a fire.

404. Rice, Raymond M., and Lisle R. Green.
1964. *The effect of former plant cover on herbaceous vegetation after fire.* J. For. 62(11):820-821.
Herbaceous cover measured on 15 lysimeters, after a fire on San Dimas Experimental Forest and consequent reseeding with ryegrass and black mustard, showed a lighter cover on pine lysimeters owing to some factor operating before or during the fire.

405. Richmond, George B.
1965. *Naturalization of Java podocarpus in Hawaii rain forest.* U.S. Forest Serv. Res. Note PSW-76, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Discusses the invasion of this tropical conifer into planted forest and undisturbed native forest as well as the possible timber uses of this tree.

406. Romberger, John A.
1960. *A suggested method for fractionation of plant extracts.* 16 p. illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Fractioning alcoholic extracts of plant tissue includes the use of ion exchange resin columns for separation into anionic, cationic and neutral fractions which are further subdivided on the basis of their pK values or solubilities by paper electrophoresis or paper chromatography.

407. Roy, Douglass F.
1955. *Hardwood sprout measurements in northwestern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 95, 6 p., illus. Berkeley, Calif.
After destruction of their aerial portions by fire or logging operations, several kinds of hardwoods produced vigorous sprouts whose height growth differed by species and number, and whose clumpage and height differed by diameter of parent tree.

408. Roy, Douglass F.
1956. *Big Douglas-fir in Northern California.* West. Conser. J. 12(4):37, illus.
Records measurements such as length, diameter, gross and net volume of board-feet, radial growth, and measurements of annual rings.

409. Roy, Douglass F.
1957. *A record of tanoak acorn and seedling production in northwestern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 124, 6 p., illus. Berkeley, Calif.
Records the number of acorns produced in 1953 by a few trees, the number of 1-year-old seedlings produced from this seed crop, and lists several birds, mammals, and some insects which feed on tanoak acorns.

410. Roy, Douglass F.
1957. *Silvical characteristics of tanoak.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 22, 21 p., illus. Berkeley, Calif.
Describes habitat conditions, the life history, and special features of this trees.

411. Roy, Douglass F.
1966. *Silvical characteristics of Monterey Pine (Pinus radiata* D. Don.) U.S. Forest Serv. Res. Paper PSW-31, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes the climatic, edaphic, physiographic, and biotic habitat conditions under which Monterey pine reproduces, grows, and dies.

412. Roy Douglass F.
1966. *Silvical characteristics of redwood (Sequoia sempervirens* (D.Don.) Endl.).
U.S. Forest Serv. Res. Paper PSW-28, 20 p., illus. Pacific Southwest Forest and Range Exp. Stn.,

Berkeley, Calif.
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413. Roy, Douglass F.
1972. *Fascination in redwood.* Madroño 21(7):462.
Corrects errors in a recent note by R. W. Becking, about the fascination—a flattening of normally cylindrical stem—in coastal redwood.

414. Roy, Douglass F., and Philip M. McDonald.
1973. *California mixed conifers.* In *Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, p. 28-31.
Summarizes silvicultural information on the mixed conifer type, which includes ponderosa pine, sugar pine, Douglas-fir, and white fir.

415. Roy, Douglass F., and Philip M. McDonald.
1973. *Pacific ponderosa pine.* In *Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, p. 31-33.
Summarizes silvicultural information on the pine type that occupies between 1 and 1½ million acres on the southern Cascade Range and Sierra Nevada, northern Coast Ranges, and the western Transvere and Peninsular Ranges.

416. Salminen, Seppo O., Athan A. Gagianas, and Arthur R. Berg.
1972. *The effect of NAA (1-napthaleneacetic acid) and morphactin (methyl 2-chloro-9-hydroxyfluorene-9-carboxylate) on RNA and protein synthesis in senescing bean endocarp.* Physiol. Plant. 26(2):186-190.
Both growth regulators studied inhibited uptake in the precursors and appeared to affect different components of the uptake mechanism.

417. Scharpf, Robert F., and J. R. Parmeter, Jr.
1962. *The collection, storage, and germination of seeds of a dwarfmistletoe.* J. For. 60(8):551-552, illus.
Seeds stored dry in paper bags remained viable longer at 36° F. than at temperatures of 5°, 56°, and 77° F.

418. Scharpf, Robert F.
1962. *Growth rate of the endophytic system of the dwarfmistletoe on Digger pine.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 193, 5 p., Berkeley, Calif.
The endophytic system was closely associated with branch swelling and the growth rate of the system was directly related to host vigor.

419. Scharpf, Robert F.
1964. *A compact system for humidity control.* Plant Dis. Rep. 148:66-67.
A modification of the system devised by Osborne and Bacon (Plant Physiol. 36:309-312. 1961) involves a humidity control obtained by circulating air directly through a diaphragm-type aquarium pump in a glycerine-water solution.

420. Scharpf, Robert F.
1965. *Flowering and seed dispersal of dwarfmistletoe, (Arceuthobium campylopodum) in California.* U.S. Forest Serv. Res. Note PSW-68, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Under the short growing season of the Sierra Nevada, both flowering and seed dispersal occurred earlier in the fall and dispersal extended for a shorter duration than at lower elevations and along the coast.

421. Scharpf, Robert F.
1970. *Seed viability, germination, and radicle growth of dwarf mistletoe in California.* USDA Forest Serv. Res. Paper PSW-59, 18 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Temperature was the most important factor affecting viability, 2° C. being the most near optimum temperature for maximum longevity in storage.

422. Schneegas, Edward R., and Eamor C. Nord.
1967. *The monarch big sagebrush of White Mountain.* J. Range Manage. 20(1):51-52, illus.
Reports the discovery of an unusually massive, big sagebrush *(Artemisia tridentata* Nutt.*)* plant almost 15 feet tall, with an average crown spread of 11 feet, and a main trunk 48 inches in circumference at ground level.

423. Schreiber, Beryl O.
1938. *Keys and charts for California species of Atriplex.* U.S. Forest Serv. California Forest and Range Exp. Stn. Tech. Paper 8, 9 p., Berkeley, Calif.
Offers a usable key with illustrations designed to facilitate field work.

424. Schreiber, Beryl O.
1939. *The genus Helianthemum in California.* Madroño 5(3):81-85.
Describes the morphology and geographic distribution of the three California species of *Helianthemum.*

425. Schreiber, Beryl O.
1940. *The Arctostaphylos canescens complex.* Am. Midl. Nat. 23(3):617-632.
Describes the geographic distribution and the peculiar

morphological characteristic which render this species readily distinguishable from other species of *Arctostaphylos*.

426. Schreiber, Beryl O.
1940. *Vegetation type map herbarium*. Chron. Bot. 6(1):19.
Briefly describes the collection of the University of California herbarium and its importance in research.

427. Schubert, Gilbert H.
1950. *Quintuplet seedlings in a sugar pine seed*. J. For. 48(2):128, 129.
Describes a rare case of polyembryony in sugar pine.

428. Schubert, Gilbert H.
1957. *Silvical characteristics of giant sequoia*. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 20, 13 p., illus. Berkeley, Calif.
Summarizes silvical information, including habitat conditions, life history, special features, horticultural clones, and distribution.

429. Schubert, Gilbert H.
1957. *Silvical characteristics of incense-cedar*. U.S. Forest Serv. California Forest and Range Exp. Stn. Tech. Paper 18, 14 p., illus. Berkeley, Calif.
Summarizes the silvical information including a description of the species, its habitat conditions, growth habits, and distribution.

430. Schubert, Gilbert H., and Nellie M. Beetham.
1962. *Silvical characteristics of giant sequoia*. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 20, 16 p., illus. Berkeley, Calif.
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431. Schubert, Thomas H., and Karl H. Korte.
1969. *Early growth and development of four pine species in Hawaii*. U.S. Forest Serv. Res. Note PSW-189, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Slash and loblolly pines have grown about twice as fast as in the Southern United States; growth of the Monterey pine is similar to that in New Zealand, Australia, and South Africa; Caribbean pine has poor form.

432. Scott, Norman C.
1964. *Moisture patterns in Douglas-fir slash*. U.S. Forest Serv. Res. Note PSW-55, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Moisture content in Douglas-fir cull logs and boles of felled tanoaks was sampled periodically at 2-inch intervals to a depth of 6 inches.

433. Seegrist, Donald W., Donald L. Neal, and Richard L. Hubbard.
1966. *Measuring bitterbrush seed production on plants with variable crown density . . . complete counts per plant suggested*. U.S. Forest Serv. Res. Note PSW-130, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Grouping seed traps relative to the plant crown did not reduce the variation of seed distribution for individual plants to an acceptable low level.

434. Siggins, H. W.
1927. *Wind carry of forest tree seeds*. Timberman 28(3):191-192.
Investigates the nature of seed transport by wind, including the distance carried, distribution and survival.

435. Siggins, H. W.
1933. *Distribution and rate of fall of conifer seeds*. J. Agric. Res. 47(2):119-128.
Determined that each species of tree produces seeds having a characteristic average rate of fall which varies considerably with the region in which the tree is grown.

436. Smith, Richard H.
1963. *Volatility and vapor saturation of pine resins*. U.S. Forest Serv. Res. Note PSW-13, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Results obtained for 10 species and 4 hybrids in California showed hybrids usually less volatile than either parent and vapor saturation ranging widely between species, slightly within a species, and hybrids usually intermediate between the two parents.

437. Smith, Richard H.
1964. *The monoterpenes of lodgepole pine oleoresin*. Phytochemistry 3(2):259-262, illus.
A gas chromatographic analysis showed: limonene—2.4 percent; sabinene—2.1 percent; an alpha-phellendrene—0.7 percent; heptane and an unidentified compound in detectable quantities.

438. Smith, Richard H.
1964. *Perennial constancy of the monoterpene synthesis in the wood oleoresin of Pinus ponderosa*. Nature. 202(4927):107-108, illus.
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439. Smith, Richard H.
1964. *Variation in the monoterpenes of Pinus ponderosa* Laws. Science 143(3612):1337-1338.
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440. Smith Richard H.
1964. *Variations in the monoterpene composition of ponderosa pine wood oleoresin.* U.S. Forest Serv. Res. Paper PSW-15, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Variations between trees in localized plots were greater than the range in average plot values and could not be associated with sample preparation analysis, position on tree of sample extraction, time of season of extraction, or storage time of sample.

441. Smith, Richard H.
1966. *The monoterpene composition of Pinus ponderosa* Laws. *xylem resin and of Dendroctonus brevicomis pitch tubes.* Forest Sci. 12(1):63-68, illus.
Compares the composition of 202 living trees with 88 fatally attacked by the beetle and finds the greatest difference in myrcene plus limonene, which was significantly higher in the living trees.

442. Smith, Richard H.
1967. *Monoterpene composition of pine species and hybrids . . . some preliminary findings.* U.S. Forest Serv. Res. Note PSW-135, 14 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A general qualitative intermediacy was found in the xylem monoterpene composition of 34 different hybrids produced by the Institute of Forest Genetics, Placerville, California.

443. Smith, Richard H.
1967. *Variations in the monoterpene composition of the wood resin of Jeffrey, Washoe, Coulter, and lodgepone pines.* Forest Sci. 13(3):246-252, illus.
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No qualitative changes were found, and only slight insignificant quantitative changes in composition could be attributed to horizontal and longitudinal positions along the main stem.

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1968. *Xylem monoterpenes of Pinus ponderosa P. washoensis, and P. jeffreyi in the Warner Mountains of California.* Madroño 21(1):26-32, illus.
Analysis suggests a physical and physiological mixing of ponderosa and Washoe pines, natural hybridization of Jeffrey and Washoe pines, an enlargement of the range of Washoe, and a close relationship between Washoe and the variation scopulorum of ponderosa.

446. Smith, Richard H., R. L. Peloquin, and P. C. Passof.
1969. *Local and regional variation in the monoterpenes of ponderosa pine wood oleoresin.* USDA Forest Serv. Res. Paper PSW-56, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
An analysis of 927 ponderosa pines showed considerable intertree diversity in composition—both locally and regionally.

447. Smith, Richard H., and Lula E. Greene.
1971. *Use of peak-heights from a fast column for rapid approximation of the normalized monoterpene composition of pine resin.* J. Chromatogr. Sci. 9:755-756, illus.
The quantitative composition of ponderosa pine xylem resin was analyzed on a fast column to record peak height and on a slow column to record peak area.

448. Stahelin, Rudolph.
1936. *Ueber den aufbau der urwaelder Kaliforniens, (The composition of the virgin forest of California.)* Bern, Buchler and Co., 1936, 11 p. Reprint from Schweiz. Ztschr. F. Forstw. Nr. 9.
Classifies and describes general forest conditions of three areas: the redwood forest of the coastal region, the pine-fir forest of the west side of the Sierra Nevada, and the pine forests of the eastern Sierra Nevada plateau.

449. Stanley, Robert G., and T. Tracewell.
1955. *Manometer flask for measuring respiratory quotients.* Science 122(3158):76-77.
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450. Stanley, Robert G.
1958. *The physiology of forest trees.* In *Methods and concepts applied to a study of flowering in pine,* p. 589-599. The Roland Press, New York.
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1958. *Terpene analysis by gas chromatography.* 133rd Meet. Am. Chem. Soc. San Francisco, Calif. p. 6A.
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1958. *Terpene formation in pine from mevalonic acid.* Nature 182(4637):738-739.
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453. Stanley, Robert G.
1958. *Terpene formation in pine.* Symposium II., Biochemistry of wood, Fourth Int. Congr. Biochem., Vienna, Austria, 1958:48-55.
The theoretical pathways by which plants may form terpenes are reviewed and a working hypothesis to explain the biogenesis of pine terpenes is offered.

454. Stanley, Robert G.
1961. *Terpene biogenesis in pine.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 56, 13 p., illus. Berkeley, Calif.
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455. Stockwell, Palmer.
1939. *Cone variation in Digger pine.* Madroño 5(2):72-73.
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457. Stone, Edward C.
1950. *Water absorption from the atmosphere by plants growing in dry soil.* Science 111(2890):546-548.
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460. Strothmann, Rudolph O.
1967. *The influence of light and moisture on the growth of red pine seedlings in Minnesota.* Forest Sci. 13(2):182-191.
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1971. *Seed fall from young growth ponderosa pine.* J. For. 69(11):790-792, illus.
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1954. *Longevity under adversity in conifers.* Science 119:883-884.
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1963. *Cupressus bakeri—an extension of the known botanical range.* Aliso 5(3):351-352.
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465. Weidman, R. H.
1947. *Trees in the Eddy Arboretum.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 53, 8 p. Berkeley, Calif.
Lists species, varieties, and hybrids, their scientific and common names, their native ranges, and the number of specimens.

466. Whitesell, Craig D.
1964. *Silvical characteristics of koa (Acacia koa Gray).* U.S. Forest Serv. Res. Paper PSW-16, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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468. Wick, Herbert L.
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1939. *Notes on the genus Arctostaphylos.* Madroño 5(1):38-47.
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471. Wold, Myron L., and Ronald M. Lanner.
1965. *New stool shoots from a 20-year old stump.* Ecology 46(5):755-756, illus.
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472. Wong, Wesley H. C., Jr.
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1966. *Forestry applications of 70 mm color.* Photogramm. Eng., 802-810, illus.
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Symp. on Remote Sensing of Environ., Univ. Mich., Ann Arbor, Proc. 1968:357-372, illus.
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1975. *Tables for the Soil-Vegetation Map of the Shasta Dam 7.5-minute quadrangle (23C-2) Shasta County, California.* 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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502. Baker, Harold L., and Adon Poli.
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noncommercial forest, and commercial forest land, with area of commercial forest land shown by timber type, age class, ownership, and size of holding.

507. Baker, Harold L., and Adon Poli.
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1955. *Area and ownership of forest land in Tehama County, California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 26, 23 p., illus. Berkeley, Calif.
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510. Bentley, Jay R., Donald W. Seegrist, and David A. Blakeman.
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512. Burgan, Robert E.
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1969. *Soil-vegetation surveys in California.* 31 p., illus. Calif. Div. For. Sacramento, Calif.
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524. Conrad, C. Eugene, and Merton J. Reed.
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525. Crawford, James M., Jr.
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1966. *Detection and classification of ash dieback on large-scale color aerial photographs.* U.S. Forest Serv. Res. Paper PSW-35, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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527. Dana, R. W.
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528. DeLapp, James A., Chester O. Stone, and W. Robert Powell.
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529. DeLapp, James A., Chester O. Stone, and W. Robert Powell.

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531. DeLapp, James A., Chester O. Stone, and W. Robert Powell.

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1916. *Forests of Yosemite, Sequoia, and General Grant National parks.* 39 p. Gov. Print. Off., Washington, D.C.
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595. Hill, Miles R., and Elliot L. Amidon.
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1964. *Hawaii forest type map. Island of Molokai.* 3 p. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., in cooperation with For. Div., Hawaii Dep. of Land and Natural Resources.
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599. Honda, Nobuo, Wesley H. C. Wong, and Robert E. Nelson.
1967. *Plantation timber on the island of Kauai, 1965.* U.S. Forest Serv. Resour. Bull. PSW-6, 34 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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600. Hornibrook, Ezra M., R. W. Larson, J. J. van Akkeren, and A. A. Hasel.
1950. *Board-foot and cubic-foot volume tables for some California hardwoods.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 67, 31 p. Berkeley, Calif.
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601. Hornibrook, Ezra M.
1951. *Tree-height chart for topographic level.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 6, 3 p. Berkeley, Calif.
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602. Horton, Jerome S.
1941. *The sample plot as a method of quantitative analysis of chaparral vegetation in California.* Ecology 22(4):457-468.
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603. Horton, Jerome S.
1960. *Vegetation types of the San Bernardino Mountains, California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 44, 29 p., illus. Berkeley, Calif.
The brush, desert scrub, and forest vegetation within 16 watersheds are described by zones and their component types.

604. Jackson, Willard L.
1961. *Board foot volumes for young-growth mixed-conifer timber.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 182, 2 p. Berkeley, Calif.
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605. Jensen, Herbert A., and Mary E. Anthony.
1937. *A new map coloring process.* J. For. 35(3):282-284.
A flexible, easily applied, permanent transparent base is an excellent medium for map coloring.

606. Jensen, Herbert A.
1939. *Vegetation types and forest conditions of the Santa Cruz Mountains unit of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 1, 55 p. Berkeley, Calif.
A narrative description of the area is accompanied by maps showing vegetation type, forest resources, and mill locations.

607. Jensen, Herbert A.
1940. *Vegetation type maps of California and western Nevada.* Science 92(2389):333.
Reports on the progress of the Forest Survey in mapping the natural vegetation resources, describes how the maps are coded, and indicates possible uses for the information presented.

608. Jensen, Herbert A.
1941. *Taking stock of California's vegetation.* Calif. Monthly, p. 10-11, 44-46.
Discusses the origin and development of the Forest Survey and vegetation type map project.

609. Jensen, Herbert A.
1947. *A system for classifying vegetation in California.* Calif. Fish and Game 33(4):199-266.
Presents a classification system designed to take advantage of aerial photography while incorporating ground mapping techniques to segregate and delineate species composition.

610. Jensen, Herbert A., and Robert N. Colwell.
1949. *Panchromatic versus infrared minus-blue aerial photography for forestry purposes in California.*

Photogramm. Eng. 15(2):201-223.
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611. Keniston, R. F., and V. A. Clements.
1943. *Taper and volume tables for ponderosa pine on site IV-100 in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 32, 9 p. Berkeley, Calif.
Presents tables to be used in cruising, appraisal, and working plans.

612. Kimmey, James W.
1950. *Cull factors for forest-tree species in northwestern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 7, 30 p. Berkeley, Calif.
Tables are presented listing the percent of cull in Douglas-fir by site and d.b.h. class, expressed in board foot volume of saw-log portion of bole, and percent of cull in white and red fir expressed in cubic foot volume of entire bole.

613. Kimmey, James M., and Ezra M. Hornibrook.
1952. *Cull and breakage factors and other tree measurement tables for redwood.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 13, 26 p. Berkeley, Calif.
Describes the use of cull and breakage factors for old-growth redwood and provides tables for taper, bark thickness, and Scribner decimal log rule extension for trees with d.b.h. greater than 90 inches.

614. Kimmey, James W.
1954. *Cull and breakage factors for pines and incense-cedar in the Sierra Nevada.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 90, 4 p. Berkeley, Calif.
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615. Kimmey, James W.
1956. *Cull factors for Sitka spruce, western hemlock, and western red cedar in southeast Alaska.* Alaska Forest Res. Center Stn. Paper 6, 31 p., illus.
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616. Kimmey, James W.
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617. Langley, Philip G.
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618. Langley, Philip G.
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619. Langley, Philip G.
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620. Langley, Philip G., Terrell D. Smith, and Ralph C. Hall.
1971. *Gross volume-tables for redwood trees in and near the Redwood National Park.* USDA Forest Serv. Res. Note PSW-256, 11 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Volume tables based on both the Spaulding and Humbolt log rules were developed for use in appraising timber.

621. Lowdermilk, W. C.
1927. *A method for rapid surveys of vegetation.* J. For. 25(2):181-185.
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622. Lund, H. Gyde, George R. Fahnestock, and John F. Wear.
1967. *Aerial photo interpretation of understories in two Oregon oak stands.* U.S. Forest Serv. Res. Note PNW-58, 6 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oregon.
Mapping by aerial photography produced results reasonably similar to those obtained by ground check.

623. Magill, Arthur W., and R. H. Twiss.
1965. *A guide for recording esthetic and biologic changes with photographs.* U.S. Forest Serv. Res. Note PSW-77, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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624. Mallory, James I., and Earl B. Alexander.
1965. *Soils and vegetation of the Lassen Peak quadrangle.* State Coop. Soil Vegetation Surv., 27 p., illus.
Describes soils and vegetation of the 13,000-acre portion of the Lassen Peak quadrangle lying outside and immediately west of the Lassen National Forest in northern California, and supplements information provided by soil-vegetation maps for this area.

625. Mallory, James I., Benjamin F. Smith, Earl B. Alexander, and Edward N. Gladish.
1965. *Soils and vegetation of the Manton quadrangle.* State Coop. Soil-Veg. Surv., 36 p., illus.
Describes soils and vegetation of the Shasta County portion of the Manton quadrangle, 30 miles east southeast of Redding, California, and supplements information provided by soil-vegetation maps for this area.

626. Mallory, James I., Chester O. Stone, Earl B. Alexander, and James M. Crawford.
1965. *Soils and vegetation of the Montgomery Creek quadrangle (22B-1,2,3,4) Shasta County, California.* State Coop. Soil-Veg. Surv., 47 p., illus.
Describes the distribution and characteristics of the soils and vegetation and their relationships for a 130,000-acre portion of the Montgomery Creek quadrangle located southeast of the Shasta-Trinity National Forest.

627. Mallory, James I., Benjamin F. Smith, Edward N. Gladish, and Earl B. Alexander.
1966. *Soils and vegetation of the Manzanita Lake quadrangle.* State Coop. Soil-Veg. Surv., 35 p., illus.
Describes the distribution and characteristics of the soils and vegetation and their relationship for a 50,000-acre portion of the Manzanita Lake quadrangle located 4 miles west of Lassen Volcanic National Park and 37 miles east of Redding in Shasta County, California.

628. Mallory, James I., Earl B. Alexander, and Edward N. Gladish.
1966. *Soils and vegetation of the Ono quadrangle.* State Coop. Soil-Veg. Surv., 50 p., illus.
Describes the distribution and characteristics of the soils and vegetation and their relationship for a 145,600-acre portion of the Ono quadrangle, and includes tables, legends, and four 7.5-minute quadrangle maps.

629. Mallory, James I., Earl B. Alexander, Wilmer L. Colwell, Jr., and W. Robert Powell.
1968. *Soils and vegetation of the Chanchelulla Peak quadrangle (31B-1,2,3,4), Shasta and Trinity Counties, California.* State Coop. Soil-Veg. Surv., 48 p., illus.
Describes the distribution and characteristics of the soils and vegetation and their relationships for a 59,000 acre portion of the Chanchelulla Peak quadrangle.

630. Mallory, James I., Wilmer L. Colwell, Jr., and W. Robert Powell.
1973. *Soils and vegetation of the French Gulch quadrangle (24D-1,2,3,4), Trinity and Shasta Counties, California.* USDA Forest Serv. Resour. Bull. PSW-12, 42 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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631. Mallory, James I., Chester O. Stone, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map southeast quarter of the Schell Mountain quadrangle (24A-4) Shasta County, California.* 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
These six tables, providing information about soil and vegetation characteristics, accompany the 7.5-minute soil-vegetation maps.

632. Mallory, James I., Chester O. Stone, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map southeast quarter of the Weaverville quadrangle (24C-4) Trinity and Shasta Counties, California.* 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 631 above.

633. Mallory, James I., Chester O. Stone, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map southwest quarter of the Weaverville quadrangle (24C-3) Trinity County, California.* 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 631 above.

634. May, Richard H.
1957. *How much forest is there? How much for how long? Coast redwood is important.* West. Conserv. J. May-June 1957:8-11, illus.
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635. Miller, Robert M.
1957. *New techniques in forestry. Machine calculation in the Forest Survey.* No. Calif. Sec. Soc. Am. For. Proc. 1956:35-41.
Describes how the punchcard method was used to compile area, volume, growth and other types of forestry data.

636. Miller, Robert M., and Sharon D. Roof.
1962. *Automatic processing of timber appraisal cruises.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 74, 25 p., illus. Berkeley, Calif.
An IBM 704 and 7090 Fortran Monitor Program has been designed to meet the needs of the timber appraiser for volume, value, and overrun of the species having net volume taper tables.

637. Myhre, Richard J., and Ralph J. Croxton.
1968. *Color contact prints from 70-mm. color film produced by small photo lab.* USDA Forest Serv. Res. Note PSW-185, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Large volumes of prints can be made by changing slightly the standard processing methods and techniques and by building special equipment to supplement existing darkroom equipment.

638. Myhre, Richard J.
1973. *Producing high-quality negatives from ERTS black-and-white transparencies.* USDA Forest Serv. Res. Note PSW-287, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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639. Neal, Robert L., Jr.
1973. *Remeasuring tree heights on permanent plots using rectangular coordinates and one angle per tree.* Forest Sci. 19(3):233-236, illus.
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640. Nelson, Robert E., K. E. Bradshaw, and A. E. Wieslander.
1957. *Photo interpretation of vegetation and soils in wild land areas of California.* Soil Sci. Soc. Am. Proc. 21(1):106-108.
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641. Nelson, Robert E.
1957. *Soil-vegetation survey of a central Sierra snow zone watershed.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 21, 43 p., illus. Berkeley, Calif.
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Summarizes statistics on forest area, timber volume, and timber harvest from the first comprehensive forest survey of Hawaii and discusses commercial timber prospects and industrial development opportunities.

643. Nelson, Robert E.
1963. *Forestry potentials in Hawaii.* In *Soil conservation in the Pacific* p. 19-21. Univ. Hawaii, Honolulu.
A summary of forestry resources and timber development possibilities, presented at 10th Pacific Science Congress Symposium in 1961.

644. Nelson, Robert E.
1964. *A look at the forests of American Samoa.* U.S. Forest Serv. Res. Note PSW-53, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Management for timber crops is feasible on about 12,000 acres of forest land with another 10,000 acres existing on such steep topography that management for protection of watershed values should be paramount.

645. Nelson, Robert E., and Nobuo Honda.
1966. *Plantation timber on the island of Hawaii—1965.* U.S. Forest Serv. Resour. Bull. PSW-3, 52 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Presents data on acreage, location, volume, quality, and ownership.

646. Nelson, Robert E.
1967. *Records and maps of forest types in Hawaii.* U.S. Forest Serv. Resour. Bull. PSW-8, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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647. Nelson, Robert E., Wesley H. C. Wong, and Herbert L. Wick.
1968. *Plantation timber on the island of Oahu—1966.*

USDA Forest Serv. Resour. Bull. PSW-10, 52 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Provides information on location and acreage of each planted stand, species composition and age, timber volume and quality, and ownership.

648. Null, William S.
1969. *Photographic interpretation of canopy density—a different approach.* J. For. 67(3):175-177, illus.
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649. O'Regan, William G., and Marshall N. Palley.
1965. *A computer technique for the study of forest sampling methods.* Forest Sci. 11(1):99-114.
An IBM 704 program was used to simulate circular plot sampling, and analytical and simulation results are compared for a simple test case.

650. O'Regan, William G.
1967. *The case against volume tables.* Conf. Young-growth Forest Manage. Proc. 1967:141-142.
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652. O'Regan, William G., and Loukas G. Arvanitis.
1969. *Sampling simulation computer programs. II. Cost-effectiveness and sampling efficiency.* Univ. Wis. Coll. Agric. and Life Sci. Res. Div. Res. Rep. 50, 31 p.
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653. O'Regan, William G., Donald W. Seegrist, and Richard L. Hubbard.
1973. *Computer simulation and vegetation sampling.* J. Wildlife Manage. 37(2):217-222, illus.
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654. Oswald, Daniel D., and Ezra M. Hornibrook.
1966. *Commercial forest area and timber volume in California, 1963.* U.S. Forest Serv. Bull. PSW-4, 16 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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655. Oswald, Daniel D., and Gerald S. Walton.
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656. Palley, Marshall N., and William G. O'Regan.
1961. *A computer technique for the study of forest sampling methods. I. Point sampling compared with line sampling.* Forest Sci. 7(3):282-294, illus.
Describes a method of stimulating point and line sampling using the IBM 701 computer and applies this method to three small forests.

657. Poli, Adon, and Donald T. Griffith.
1948. *Forest land ownership in northern Mendocino County, California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 5, 49 p. Berkeley, Calif.
Presents detailed tables illustrating the complex pattern of land ownership including the types of owner, reasons for acquiring land, present use and proposed future use.

658. Poli, Adon.
1952. *Conducting a survey of ownership of forest land in California.* Agric. Econ. Res. 4(1):8-12.
Describes the use of line-sampling in a forest ownership survey of Mendocino County.

659. Poli, Adon, and Harold L. Baker.
1954. *Ownership and use of forest land in the Redwood—Douglas-fir subregion of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 7, 76 p. Berkeley, California.
Discusses ownership in relation to use of forest land, types of owners, size of holdings, operating tenure, how acquired, how used, and effect of ownership on management.

660. Poli, Adon.
1956. *Ownership and use of forest land in northwestern California.* Land Econ. 32(2):144-151, illus.
Summarizes and interprets results of forest land ownership studies in the northern coastal counties of California.

661. Powers, Robert F.
1969. *Estimating past diameters of ponderosa pine in*

northern California. USDA Forest Serv. Res. Note PSW-194, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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662. Ratliff, Raymond D., and Stanley E. Westfall.
1973. *A simple stereophotographic technique for analyzing small plots.* J. Range Manage. 26(2):147-148, illus.
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663. Reineke, L. H.
1930. *The effect of composition on yield of mixed-conifer stands in the Sierras.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 2, 2 p. Berkeley, Calif.
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664. Reineke, L. H.
1932. *A precision dendrometer.* J. For. 30(6):692-699.
A screw hook and micrometer serves as a simple, accurate, and inexpensive nonrecording mechanism for measuring growth.

665. Reineke, L. H.
1933. *Perfecting a stand-density index for even-aged forests.* J. Agric. Res. 46(7):627-638.
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666. Retzer, J. L., and E. A. Colman.
1955. *Soil surveys on forest and range lands.* U.S. Dep. Agric. Yearb. 1955:242-246, illus.
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667. Richards, Lucille G.
1959. *Forest densities, openings, ground cover, and slopes in the snow zone of the Sierra west-side.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 40, 21 p., illus. Berkeley, Calif.
Reports densities, extent of openings and of brush cover, and slope steepness and exposure, as determined from aerial photos and topographic maps.

668. Richards, Lucille G.
1961. *Terrain features of drainage basins in the Sierra Nevada west-side snow zone.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 58, 11 p., illus. Berkeley, Calif.
Gives a breakdown by individual drainage basins of ground and cover characteristics which had previously been inventoried for the area as a whole.

669. Roof, Sharon D., and Clyde Shumway.
1961. *An IBM 704 computer program for polynomial computed points.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 183, 2 p. Berkeley, Calif.
An equation in three arguments, each to the sixth power, is solved for any range of the arguments, and a table is printed.

670. Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon.
[illegible] *[illegible]ildland Resource Information System: user's guide.* USDA Forest Serv. Gen. Tech. Rep. PSW-10, 36 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Covers the preparation of maps, digitizing them manually or by raster scanning, editing, and computer processing of polygon boundaries.

671. Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon.
[illegible] *[illegible] a resource [illegible]rmation system for wildland management.* USDA Forest Serv. Res. Paper PSW-107, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes the design, development, testing, and implementation of a geographic information system and provides an overview for managers responsible for natural resource planning.

672. Sharpnack, David A.
1965. *A computer trial of 3-p sampling.* Soc. Am. For. Proc. 1964:225-226.
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673. Sharpnack, David A.
1966. *Predicting volumes in four Hawaii hardwoods . . . first multivariate equations developed.* U.S. Forest Serv. Res. Note PSW-121, 15 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Equations predict volumes for koa, ohia, robusta eucalyptus, and saligna eucalyptus.

674. Sharpnack, David A., and Garth Akin.
1969. *An algorithm for computing slope and aspect from elevations.* Photogramm. Eng. 35(3):247-248, illus.

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1973. *The changing forest base.* Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc., Portland, Oreg. 1973:162-164.
Describes the work flow used on inventories for two National Forests, using the Wildland Resources Information System.

676. Shephard, Ronald W.
1964. *Final summary report on Forest Service operations.* Univ. Calif. Oper. Res. Center Orc 65-3(PR), 10 p.
The lumber cut for California during 1932 was 277,318 m bd. ft. less than that in 1931, and was 71 percent of the cut of that year and 44.9 percent of that of 1930.

677. Smith, Benjamin F., James I. Mallory, and W. Robert Powell.
1974. *Tables for the Soil-Vegetation Map, northeast quarter of the Gridley quadrangle (49A-1), Butte County, California.* 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
These six tables, providing information about soil and vegetation characteristics, accompany the 7.5-minute Soil-Vegetation Maps.

678. Smith, Benjamin F., James I. Mallory, and W. Robert Powell.
1974. *Tables for the Soil-Vegetation Map, southeast quarter, Gridley quadrangle (49A-4) Butte County, California.* 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

679. Smith, Benjamin F., James I. Mallory, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map northwest quarter of the Nevada City quadrangle (50A-2) Yuba County, California.* 18 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

680. Stone, Chester O., James I. Mallory, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map southwest quarter of the Trinity Dam (24B-3) and northwest quarter of the Weaverville quadrangle (24C-2), Trinity County, California.* 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

681. Stone, Chester O., James A. DeLapp, and W. Robert Powell.
1974. *Tables for the Soil-Vegetation Map, northwest quarter of the Big Meadow quadrangle (69A-2) Calaveras County, California.* 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

682. Stone, Chester O., and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map LaGrange 7.5 minute quadrangle, (78C-2) and the Cooperstown 7.5 minute quadrangle (79D-1) Tuolumne County, California.* 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

683. Stone, Chester O., James A. DeLapp, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map northeast quarter of the Blue Mountain quadrangle (69B-1) Calaveras County, California.* 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

684. Stone, Chester O., James A. DeLapp, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map northeast quarter of the Copperopolis quadrangle (79A-1) Calaveras and Tuolumne Counties, California.* 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

685. Stone, Chester O., James I. Mallory, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map northeast quarter of the Weaverville quadrangle (24C-1) Shasta and Trinity Counties, California.* 19 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

686. Stone, Chester O., James A. DeLapp, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map northwest quarter of the Blue Mountain quadrangle (69B-2) Calaveras County, California.* 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

687. Stone, Chester O., James A. DeLapp, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map southeast*

quarter of the Copperopolis quadrangle (79A-4) Tuolumne County, California. 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

688. Stone, Chester O., James A. DeLapp, Benjamin F. Smith, and W. Robert Powell.
1975. *Tables for the Soil-Vegetation Map southeast quarter of the San Andreas quadrangle (68D-4) Calaveras and Tuolumne Counties, California.* 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
See item 677 above.

689. Stone, Chester O., and W. Robert Powell.
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See item 677 above.

690. Stone, Chester O., and James I. Mallory.
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691. Stone, Chester O., James I. Mallory, and W. Robert Powell.
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693. Sundahl, William E.
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694. Sundahl, William E.
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1971. *Automated mapping of forest resources from digitized aerial photographs.* In *Applications of remote sensing in forestry,* p. 177-188, illus. Int. Union For. Res. Organ. Sec. 25, Freiburg.
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705. Walton, Gerald S., and C. J. DeMars.
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1965. *Aerial volume table for estimating cubic foot losses of white spruce and balsam fir in Minnesota.* J. For. 63(1):25-29.
Photo measurements of average stand height of dominant and codominant host trees and crown closure percentage were found to have a high correlation with cubic volumes of the dead host trees.

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715. Wert, Steven L., and Bruce Roettgering.
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1935. *First steps of the forest survey in California.* J. For. 33(10):877-884.
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734. Wilson, Richard C.
1941. *Vegetation types and forest conditions of Douglas and Ormsby Counties and southwestern Washoe County, Nevada.* U.S.Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 2, 61 p. Berkeley, Calif.
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735. Wilson, Richard C.
1967. *Space photography for forestry.* Photogramm. Eng., p. 483-490, illus.
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1962. *The soil-vegetation survey as a means of classifying land for multiple-use forestry.* Fifth World For. Congr. Proc. Vol. I:542-546.
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FOREST MANAGEMENT

Forest Genetics

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742. Austin, Lloyd.
1928. *Breeding pines for more rapid growth.* J. Hered. 19(7):289-301.
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1928. *Experiments at Eddy tree breeding station.* Timberman 29(7):42,44.
Describes work concerned mainly with selection and pollination.

744. Austin, Lloyd.
1929. *The Eddy tree breeding station.* Madroño 1(15):203-212.
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746. Austin, Lloyd.
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753. Bingham, W. E., S. L. Krugman, and E. F. Estermann.
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1945. *Embryological aspects of hybrid vigor in pines.* Science 102(2641):135-142.
Concludes that a hybrid embryo larger than that of the parents is the result rather than the cause of hybrid vigor.

755. Callaham, Robert Z.
1956. *Needle oils of three pine species and species hybrids.* Forest Sci. 2(2):101-105.
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756. Callaham, Robert Z.
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757. Callaham, Robert Z., and A. A. Hasel.
1958. *Height growth of ponderosa pine progenies.* Soc. Am. For. Proc. 1957:61-62.
Discusses the interrelationships of seed-size, germination, height growth, crop year, and elevation.

758. Callaham, Robert Z., and Woodbridge Metcalf.
1959. *Altitudinal races of Pinus ponderosa confirmed.* J. For. 57(7):500-502, illus.
At 20 years of age, ponderosa and Jeffrey pines under test in the North Coast Range of California showed an essentially similar relation between vigor and elevation of seed-source as when tested for 12 years at different elevations in the Sierra Nevada.

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1960. *Observations on pine susceptibility to weevils.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 51, 12 p. Berkeley, Calif.
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Progenies of seed trees growing between 1000 and 2000 feet grew best at low (960 feet) and medium (2730 feet) elevation plantations whereas at 5650 feet the progenies from lower elevations seemed to be falling behind.

761. Callaham, Robert Z., and A. A. Hasel.
1961. *Pinus ponderosa—height growth of wind-pollinated progenies.* Silvae Genetica 10(2):33-42, illus.
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1961. *Stretching the pollen supply.* J. For. 59(3):204-207, illus.
Results from a test using dilutions of pollen in controlled pollinations of Jeffrey and ponderosa pines suggest that dilution to 50 percent viable pollen may not reduce seed production.

763. Callaham, Robert Z.
1962. *Geographic variability in growth of forest trees.* In *Tree growth.* p. 311-325, illus. The Ronald Press Co., New York.
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764. Callaham, Robert Z.
1962. *Resistance of three interspecific white pine hybrids to blister rust.* J. For. 60(6):409-410.
Resistance of hybrids was directly related to resistance of the parental species: *Pinus monticola* Dougl., very susceptible: *P. strobus* L., susceptible; and *P. griffithii* McClell., resistant.

765. Callaham, Robert Z., and John W. Duffield.
1963. *Heights of selected ponderosa pine seedlings during 20 years.* Forest Genet. Workshop Proc. 1962:10-13. (South Forest Tree Improv. Comm. Publ. 22, Macon, Ga.)
Seedlings selected within a one-parent progeny according to the length of the epicotyl showed no relation between tree height and epicotyl length or number and length of cotyledons, although length of cotyledons accounted for 20 percent of height at 2 years.

766. Callaham, Robert Z.
1964. *Provenance research: investigation of genetic diversity associated with geography.* Unasylva 18(2-3):73-74.

Reviews concepts of the species, of variation within species, and of the relation of this variation to environment.

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1966. *Hybridizing pines with diluted pollen.* Proc. Eighth South. Conf. Forest Tree Improv. 1965:110-111.
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768. Callaham, Robert Z.
1966. *Nature of resistance of pines to bark beetles.* Proc. N.A.T.O. and N.S.F. Symp. 1964:197-201, illus.
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769. Callaham, Robert Z.
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1966. *Pine pollens frozen five years produce seed.* U.S. Forest Serv. Res. Paper NC-6, p. 94-101. North Central Forest Exp. Stn. St. Paul, Minn.
Pollens from different trees varied in ability to produce seeds after freezing; pollens refrigerated at 5° C. rapidly lost their ability to produce seed.

771. Callaham, Robert Z.
1967. *Hybridizing pines with diluted pollen.* Silvae Genetica 16(4):121-125, illus.
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773. Conkle, M. Thompson.
1971. *Inheritance of alcohol dehydrogenase and leucine aminopeptidase isozymes in knobcone pine.* Forest Sci. 17(2):190-194, illus.
A new technique of starch gel electrophoresis and staining for separating and making visible enzymes from embryos at germination has been developed.

774. Conkle, M. Thompson.
1971. *Isozyme specificity during germination and early growth of knobcone pine.* Forest Sci. 17(4):494-498, illus.
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775. Conkle, M. Thompson.
1972. *Analyzing genetic diversity in conifers . . . isozyme resolution by starch gel electrophoresis.* USDA Forest Serv. Res. Note PSW-264, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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776. Conkle, M. Thompson.
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1973. *Growth data for 29 years from the California elevational transect study of ponderosa pine.* Forest Sci. 19(1):31-39, illus.
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778. Conkle, M. Thompson.
1974. *Enzyme polymorphism in forest trees.* In *Third Am. Forest Biol. Workshop, Colo. State Univ., Sept. 9-12, 1974,* p. 95-105, illus.
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The color reaction provided a measure of germination which, in fresh pollen, correlates fairly well with that of

the more laborious germination procedures commonly used.

780. Coyne, John F., and William B. Critchfield.
1974. *Identity and terpene composition of Honduran pines attacked by the bark beetle Dendroctonus frontalis (Scolytidae).* Turrialba 24(3):327-331.
Tree hosts for the large epidemic in Honduras from 1963 to 1966 were identified as *Pinus oocarpa, P. Caribaea* var. *hondurensis* and *P. tenifolia.*

781. Critchfield, William B.
1963. *The Austrian × red pine hybrid.* Silvae Genetica 12(6):187-192, illus.
Discusses the 1955 cross of *Pinus nigra* and *P. resinosa* at the Institute of Forest Genetics, and analyzes the effect of weather on pollen ripening.

782. Critchfield, William B.
1963. *Hybridization of the southern pines in California. Forest Gent. Workshop Proc. 1962:40-48.* Southern Forest Tree Improvement Com. Pub. 22, Macon, Ga.
Presents results of the crosses of 16 species pairs, and suggests that southern pines are not closely related to western species, contrary to former belief.

783. Critchfield, William B.
1965. *A new hybrid Christmas tree.* Southern Lumberman, 211(2632):132-133, illus.
Describes *Pinus contorta* intra-species cross and plans to test its adaptability for Christmas tree production.

784. Critchfield, William B.
1966. *Crossability and relationships of the California big-cone pines.* U.S. Forest Serv. Res. Paper NC-6, p. 36-44. North Central Forest Exp. Stn., St. Paul, Minn.
Reports on hybridization studies that have helped clarify the relationships of the California big-cone pines.

785. Critchfield, William B.
1966. *Phenological notes on Latin American Pinus and Abies.* J. Arnold Arbor. 47(4):313-318.
Reports observations on the time of pollen shedding in two species of *Abies* and 14 species and varieties of *Pinus.*

786. Critchfield, William B.
1967. *Crossability and relationships of the closed-cone pines.* Silvae Genetica 16(3):89-97, illus.
A long-term program of species hybridization at the Institute of Forest Genetics at Placerville, California, is aimed at clarifying the relationships of the closed-cone pine group.

787. Critchfield, William B., and Stanley L. Krugman.
1967. *Crossing the western pines at Placerville, California.* Arbor. Bull. 30(4):78-81, 92, illus.
Hard pines can generally be crossed successfully only with similar species native to the same part of the world whereas soft pines of the Western Hemisphere have been crossed successfully with soft pines of the Eastern Hemisphere.

788. Critchfield, William B.
1975. *Interspecific hybridization in Pinus: a summary review. In, Symposium on Interspecific and Interprovenance Hybridization in Forest Trees.* D. P. Fowler and C. W. Yeatman, ed. Proc. 14th Meet. Can. Tree Improv. Assoc., Part 2, 1975.
Pinus does not appear to be very different from many other genera in the ability of its species to cross with each other, but it does differ in the fertility of its hybrids.

789. Cumming, W. C., and F. I. Righter.
1948. *Methods used to control pollination of pines in the Sierra Nevada of California.* U.S. Dep. Agric. Circ. No. 792, 18 p. U.S. Gov. Print. Off. Washington, D.C.
Outlines techniques including how to isolate the ovulate flowers, collecting and preparing pollen for use, pollination procedures, and protecting cones and seeds.

790. Day, Besse B., and Lloyd Austin.
1939. *A three-dimensional lattice design for studies in forest genetics.* J. Agric. Res. 59(2):101-119.
Presents a progeny test method which minimizes variables in the selection of seed trees for the improvement of the strains of timber trees.

791. Day, Besse B., and Lloyd Austin.
1941. *The use of the three-dimensional quasi-factorial design for testing a large number of Pinus ponderosa varieties.* Proc. Seventh Int. Congr. Genet. Edinburgh, 1939:98-99.
Reports on the effectiveness of the design for eliminating variations in two principal measurements, two-year height and diameter.

792. Duffield, John W.
1947. *Dates and places of pollen collection by the Institute of Forest Genetics.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 56, 5 p. Berkeley, Calif.
Includes notes on collection techniques and presents a table compiled from 10-year breeding records, furnishing dates and places of pollen collection.

793. Duffield, John W., and Palmer Stockwell.
1949. *Pine breeding in the United States.* U.S. Dep. Agric. Yearb. 1949:147-153.

Hybrids and strains of superior growth rate, hardiness, insect resistance, gum yield, and other qualities have been produced with trees from widely separate localities.

794. Duffield, John W., and A. R. Liddicoet.
1949. *Variability of rooting in a small second generation population of the hybrid Pinus attenuradiata.* J. For. 47(2):107-109.
Wide differences in rooting ability among members of the hybrid population corresponded in 2 successive years, thus indicating that individuals may be selected which can be readily propagated by cuttings.

795. Duffield, John W.
1950. *Techniques and possibilities for Douglas-fir breeding.* J. For. 48(1):41-45.
Recommends a new technique used to control pollination in breeding programs.

796. Duffield, John W.
1952. *Relationships and species hybridization in the genus Pinus.* Ztschr. Fur Forstgenetick und Forstpflanzenzuchtung 1(4):93-97.
Recommends a scheme to indicate species with the greatest degree of "crossability".

797. Duffield, John W., and Francis I. Righter.
1953. *Annotated list of pine hybrids made at the Institute of Forest Genetics.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 86, 9 p. Berkeley, Calif.
Lists hybrids by common names of parental species with short descriptions of each.

798. Duffield, John W.
1953. *It's the ancestor that makes the tree.* Am. Forests 59(11):37, 46-47.
Recent trends in forest products utilization have placed a high priority on the genetic improvement of forest trees for the development of intensified silvicultural practices.

799. Duffield, John W.
1953. *Pine pollen collection dates—annual and geographic variation.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 85, 9 p. Berkeley, Calif.
Gives dates and places of collection by the Institute of Forest Genetics, Placerville, Calif., and describes the resulting hybrids.

800. Duffield, John W., and Robert Z. Callaham.
1959. *Deep-freezing pine pollen.* Silvae Genetica 8(1):22-24.
Presents method and results of deep-freezing pollen of seven species.

801. Franklin, E. C., and Robert Z. Callaham.
1970. *Multinodality, branching, and forking in lodgepole pine (Pinus contorta* var. Murrayana Engelm.). Silvae Genetica 19(5):180-184, illus.
Genetic control of branching and forking traits was indicated from a study in six wind- and nine control-pollinated 6-year-old families.

802. Griffin, James R., and M. Thompson Conkle.
1967. *Early performance of knobcone × Monterey hybrids . . . on marginal timber sites.* U.S. Forest Serv. Res. Note PSW-156, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Hybrids appear more promising than either parents in plantations at 2200 to 3200 feet elevation; damage from snow and windthrow suggests high risk of storm damage to hybrids planted at higher elevations.

803. Griffin, James R.
1971. *Variability of germination in Digger pine in California.* USDA Forest Serv. Res. Note PSW-248, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Unstratified seeds germinated slowly; germination of stratified seeds revealed distinct population differences.

804. Haagen-Smit, A. J., C. T. Redemann, and N. T. Mirov.
1947. *Composition of gum turpentine of Torrey pine.* Am. Chem. Soc. J. 69(8):2014-2017.
Physical constants of typical samples are presented together with data showing yields of turpentine from an an average tree.

805. Haagen-Smit, A. J., C. T. Redemann, T. H. Wang, and N. T. Mirov.
1950. *Composition of gum turpentines of pines, a report on Pinus ponderosa, P. banksiana, P. canariensis, canariensis, and P. washoensis.* J. Am. Pharm. Ass- 39(5):260-265.
Reports chemical analysis later summarized *Composition of gum turpentines of pines,* USDA Tech. Bull. 1239(1961).

806. Haagen-Smit, A. J., T. H. Wang, and N. T. Mirov.
1950. *Composition of gum turpentines of Pinus aristata, P. balfouriana, P. flexilis, and P. parviflora.* J. Am. Pharm. Assoc. Sci. Ed. 39(5):254-259.
See item 805 above.

807. Haagen-Smit, A. J., T. H. Wang, and N. T. Mirov.
1951. *Composition of gum turpentines of pines. XIII. A A report on Pinus albicaulis.* J. Am. Pharm. Assoc. Sci. Ed. 40(11):557-559.
See item 805 above.

808. Hall, Ralph C.
1959. *Field tests of the resistance of hybrid pines to the pine reproduction weevil.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 33, 21 p., illus. Berkeley, Calif.
The backcross hybrid of Jeffrey and Coulter pines showed a marked resistance to pine reproduction weevil attacks when tested from 1948 through 1956 on three field plantings in northern California.

809. Iloff, P. M., Jr., and N. T. Mirov.
1953. *Composition of gum turpentines of pines. XVI. A report on Pinus oocarpa and P. pseudostrobus* var. *oaxacana from Chiapas and P. cooperi from Durango.* J. Am. Pharm. Assoc., Sci. Ed. 42(1):46-49.
See item 805 above.

810. Iloff, P. M., Jr., and N. T. Mirov.
1953. *Composition of gum turpentines of pines. XVII. A report on Pinus montezumae from Chiapas and P. oocarpa* var. *trifoliata and P. durangensis from Durango, Mexico.* J. Am. Pharm. Assoc., Sci. Ed. 42(8):464-467.
See item 805 above.

811. Iloff, P. M., Jr., and N. T. Mirov.
1954. *Composition of gum turpentines of pines. XXI. A report on Pinus quadrifolia from southern California, P. Lumholtzii, from Durango, Mexico, and P. caribaea from Nicaragua.* J. Am. Pharm. Assoc. Sci. Ed. 43(12):738-741.
Gives methods and results of turpentine analyses which showed that Caribbean pines from Nicaragua differ considerably from slash pine of Southeastern United States.

812. Iloff, P. M., Jr., and N. T. Mirov.
1954. *Composition of gum turpentines of pines XXII. A report on Pinus rudis and P. hartwegii from Mexico and P. insularis from the Philippines.* J. Am. Pharm. Assoc. Sci. Ed. 43(12):742-745.
Gives methods and results of turpentine analyses which suggested that Rudis pine and Hastweg's pine should not be considered merely varieties of Montezuma pine but rather as independent species.

813. Iloff, P. M., Jr., and N. T. Mirov.
1954. *Composition of gum turpentines of pines, XIX. A A report on Pinus ponderosa from Arizona, Colorado, South Dakota and northern Idaho.* J. Assoc. Sci. Ed. 43(6):373-378.
Results from analysis provide a basis for distinguishing three forms of ponderosa pine: a Pacific Coast form, an Intermountain form, and an east-of-the-Rockies form.

814. Jenkinson, James L.
1974. *Ponderosa pine progenies: differential response to ultramafic and granitic soils.* USDA Forest Serv. Res. Paper PSW-101, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Growth differences among progenies tested were related to differences in their ability to take up calcium from soils that are low in available calcium.

815. Jenkinson, James L.
1975. *Increasing planting stock size by family selection in California ponderosa pine.* USDA Forest Serv. Res. Paper PSW-108, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
After one growing season, inherent height growth differences among families from within stands were evident, after two seasons, volume growth among families from single stands and areas ranged from 76-133 to 44-161 percent of the area mean.

816. Johnson, LeRoy C.
1969. *FTI (Forest Tree Improvement) in California traced from 1925.* Forest Indus. 96(4):33, illus.
Research on individual tree and geographical/elevational races has contributed to the emphasis that is presently placed on single tree selection for seed orchards and on identifying select stands for cone collecting.

817. Johnson, LeRoy C., and Leroy C. Saylor.
1972. *El Dorado pine: an aneuploid Monterey pine cultivar.* J. Hered. 63(5):293-296, illus.
Pinus radiata "El Dorado" cv. nov. is so distinctly different from normal Monterey pine that it should be named as a cultivar.

818. Johnson, LeRoy C.
1974. *Hybrid Christmas trees, good news—bad news.* Calif. Christmas Tree Growers Assoc. Bull. 89, p. 19-22.
Even though specific tree-by-tree crosses that result in high production have been identified, it is not feasible now for commercial tree breeders to use either the pollen or seed parents.

819. Johnson, LeRoy C., and William B. Critchfield.
1974. *A white-pollen variant of bristlecone pine.* J. Hered. 65(2):123.
A variant of bristlecone pine more than 2500 years old, growing in the Schulman Grove, White Mountains, California, produces white pollen rather than the usual yellow pollen.

820. Keng, Hsuan, and Elbert L. Little, Jr.
1961. *Needle characters of hybrid pines at Institute of*

Forest Genetics, Placerville, California. Silvae Genetica 10(5):131-146, illus.
Gross morphology and microscopic anatomy of needles of 43 pine hybrids are described, with needle characters presented in 18 tables to facilitate identification of hybrids.

821. Kinloch, Bohun B., Jr., Gaylord K. Parks, and Carl W. Fowler.
1970. *White pine blister rust, simply inherited resistance in sugar pine.* Science 167:193-195, illus.
Segregation ratios of offspring from four disease free sugar pines suggest that resistance is under major gene control and simply inherited.

822. Kinloch, Bohun B., Jr.
1972. *Genetic variation in resistance to cronartium and peridermium rusts in hard pines.* In *Biology of rust resistance in forest trees.* U.S. Dep. Agric. Misc. Publ. 1221, p. 445-462, illus.
New approaches to the analysis of genetic interactions between hosts and pathogens in wild, heterozygous populations are discussed in the context of the gene-for-gene theory.

823. Krugman, Stanley L.
1963. *Ten-year performance of a California planting of progenies of 'elite' and 'non-elite' Pinus radiata from Australia.* U.S. Forest Serv. Res. Note PSW-32, 2 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
After 10 years there is still no evidence, from diameter and height growth and branching habit, that the two outstanding phenotypes from Australia produce genetically superior wind-pollinated progenies for California planting.

824. Krugman, Stanley L.
1970. *Incompatibility and inviability systems among some Western North American pines.* Proc. Sexual Reprod. of Forest Trees, IUFRO Sec. 22, Working Group, Finland 1970:13 p.
Summarizes the reproductive barriers found in the species reciprocal crossing of four western hard pines— Jeffrey, ponderosa, Rocky Mountain ponderosa, and Coulter pine—and one soft pine—western white pine.

825. Lanner, Ronald M.
1962. *Controlling the moisture content of conifer pollen.* Silvae Genetica 11(4):114-117.
Reports tests with pollen of nine species of *Pinus, Abies, Pseudotsuga,* and *Cedrus* which provided a method for achieving a predetermined moisture content.

826. Lanner, Ronald M., and Stanley L. Krugman.
1963. *Abies: a bibliography of literature for tree improvement workers.* U.S. Forest Serv. Res. Paper PSW-10, 25 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Lists 373 references pertaining to tree improvement.

827. Liddicoet, A. R.
1948. *Pinus: pollination bag construction.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 57, 4 p. Berkeley, Calif.
Outlines plans for constructing a bag used to cover the female flowers excluding air-borne pollen, yet porous enough to allow moisture to be dissipated and with a window for examining the conelets without removing the bag.

828. Linhart, Y. B., B. Burr, and M. Thompson Conkle.
1967. *The closed-cone pines of the Northern Channel Islands.* Symp. on Biology of the Calif. Islands, Santa Barbara Bot. Gardens, Proc. 1966:151-177, illus.
Describes the populations and includes analyses of data from collected specimen as well as related mainland populations of *Pinus muricata.*

829. Little, Elbert L., Jr., and Francis I. Righter.
1965. *Botanical descriptions of 40 artificial pine hybrids.* U.S. Dep. Agric. Tech. Bull. 1345, 47 p., illus.
Provides botanical descriptions of 40 artificial first-generation pine hybrids growing at the Institute of Forest Genetics, Placerville, Calif.

830. McMinn, H. E., E. B. Babcock, and Francis I. Righter.
1949. *The Chase oak, a new giant hybrid oak from Santa Clara County, California.* Madroño 10(2):51-55.
Describes *Quercus chasei,* a giant hybrid between *Quercus agrifolia* and *Quercus kelloggii.*

831. Miller, J. M.
1950. *Resistance of pine hybrids to the pine reproduction weevil.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 68, 17 p. Berkeley, Calif.
Lists 10 hybrids and species of pines which are resistant and suggests further work be directed to field trials of these trees.

832. Mirov, N. T.
1929. *Chemical analysis of the oleoresins as a means of distinguishing Jeffrey pine and western yellow pine.* J. For. 27(2):176-187.
Studies in differentiation indicate that when the morphological characters overlap widely, the only diagnostic character which is constant and stable is the chemical composition of the oleoresins.

833. Mirov, N. T.
1932. *A note on Jeffrey and western yellow pine.* J. For. 30(1):93,94.
Calls attention to a yellow pine that shows certain of the morphological characters of Jeffrey pine and also describes a twin tree formed by the union of a Jeffrey and western yellow pine.

834. Mirov, N. T.
1937. *Application of plant physiology to the problems of forest genetics.* J. For. 35(9):840-844.
Discusses how to apply principles of plant physiology to develop better strains of trees without hybridization.

835. Mirov, N. T.
1938. *Phylogenetic relations of Pinus jeffreyi and Pinus ponderosa.* Madroño 4(6):169-171.
Points to evidence in the chemical composition of seed oil that *Pinus jeffreyi* has a more ancient origin than *Pinus ponderosa.*

836. Mirov, N. T., and Palmer Stockwell.
1939. *Colchicine treatment of pine seeds.* J. Hered. 30(9):389-390.
Most of the treated seeds showed delayed development resulting in weak seedlings with swollen crowns; however, it may be possible to produce stable polyploid plants that can be used in breeding.

837. Mirov, N. T.
1941. *Forest genetics: Present status and outlook for the future.* Pacific Sci. Congr. 6th, Berkeley, Stanford, and San Francisco, 1939. Proc. 4:727-730.
Outlines past investigation into improving forests through genetics and developing superior trees by hybridization.

838. Mirov, N. T.
1942. *Possibility of simple biochemical tests for differentiation between species of genus Pinus.* J. For. 40(12):953-954.
Reports the identification of *Pinus jeffreyi* and *Pinus ponderosa* based upon a simple colorimetric test of their pitch.

839. Mirov, N. T.
1946. *Composition of gum turpentine of Coulter pine.* Indus. Eng. Chem. 38(4):405-408.
Analysis revealed two terpenes and two paraffin hydrocarbons, indicating that turpentine obtained from pine oleoresins is not always a mixture of terpenes alone.

840. Mirov, N. T.
1946. *Pinus: a contribution of turpentine chemistry to dendrology and forest genetics.* J. For. 44(1):13-16.
The pattern of occurrence of different chemical compounds in the turpentines facilitates the delineation of phylogenetic relationships.

841. Mirov, N. T.
1947. *Composition of gum turpentine of bishop pine.* J. For. 45(9):659-660.
The turpentine obtained from oleoresin consists almost entirely of D-α-pinene.

842. Mirov, N. T.
1948. *The terpenes (in relation to the biology of genus Pinus).* Annu. Rev. Biochem. 1948, Vol. 17:521-540.
Discusses the status of biochemistry of turpentines, and includes tables demonstrating that taxonomic and phylogenetic information can be obtained through biochemical analysis.

843, Mirov, N. T., T. H. Wang, and A. J. Haagen-Smit.
1949. *Chemical composition of gum turpentines of pines: a report on Pinus strobus, P. cembra, P. taeda, P. radiata, and P. virginiana.* J. Am. Pharm. Assoc. Sci. Ed. 43(6):373-378.
Composition of turpentines of the five pine species studied is simple, consisting in four cases chiefly of α and β pinenes and in one case *(P. virginiana)* of α pinene alone.

844. Mirov, N. T., and A. J. Haagen-Smit.
1949. *Composition of gum turpentine of knobcone pine.* J. For. 47(9):721-722.
The turpentine of *Pinus attenuata* differs from bishop pine by the total absence of camphene.

845. Mirov, N. T., A. J. Haagen-Smit, and James Thurlow.
1949. *Composition of gum turpentine of Pinus lambertiana.* J. Am. Pharm. Assoc. Sci. Ed. 38(7):407-409.
Results indicate the presence of 65 percent L-α-pinene and 13 percent L-β-pinene and other compounds in proportions different than those ascertained by previous investigators.

846. Mirov, N. T.
1951. *Composicion quimica del aguarras de los tres pinos de michoacan. (Chemical composition of the terpentines of the Michoacan pines.)* El Mensajero For., Nov. 1951:5, 16.
Reports density, refractive index, optical rotation and composition of *Pinus montezumae, P. oocaipa* and *P. leiophylla.*

847. Mirov, N. T.
1951. *Composition of gum turpentines of pines. XII. A report on Pinus echinata, P. rigida, and P.*

leiophylla. J. Am. Pharm. Assoc. Sci. Ed. 40(11):550-551.
Gives methods and results of oleoresin analysis as part of turpentine inventory studies.

848. Mirov, N. T.
1951. *Composition of gum turpentines of pines: A report on Pinus echinata, P. rigida, and P. ponderosa from Utah.* J. Am. Pharm. Assoc. Sci. Ed. 40(8):410-413.
See item 847 above.

849. Mirov, N. T.
1951. *Inducing early production of pine pollen.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 80, 3 p. Berkeley, Calif.
Grafting seedlings onto a mature ponderosa pine induced early formation of flowers and pollen for four pines—Torrey, lodgepole, Digger, ponderosa—and a hybrid of Jeffrey and Coulter pines.

850. Mirov, N. T., J. W. Duffield, and A. R. Liddicoet.
1952. *Altitudinal races of Pinus ponderosa—a 12 year progress report.* J. For. 50(11):825-831.
Seeds from trees between 1500 and 3000 feet elevation produced progeny with greater growth rates and hardiness than progeny of trees from other elevations.

851. Mirov, N. T.
1952. *Composition of gum turpentines of pines. XIV. A report on three Mexican pines, Pinus ayacahuite, P. cembroides, and P. pinceana.* J. Am. Pharm. Assoc. Sci. Ed. 41(12):673-676.
See item 847 above.

852. Mirov, N. T.
1952. *Composition of gum turpentines of pines. XV. A report on Pinus resinosa and Pinus reflexa.* J. Am. Pharm. Assoc. Sci. Ed. 41(12):677-679.
See item 847 above.

853. Mirov, N. T.
1953. *Chemical aspects of diploxylon pines.* Ztschr. f. Forstgenetik u. Forstpflanzenzuchtung 2(5):93-96.
Chemical analysis of turpentines supports G. R. Shaw's 1914 taxonomy of the genus *Pinus.*

854. Mirov, N. T.
1953. *Taxonomy and chemistry of the white pines.* Madroño 12(3):81-89.
Extensive taxonomy based on the chemical relationship of the gums of the trees in section haploxylon of the genus *Pinus.*

855. Mirov, N. T.
1954. *Apache pine and its relation to ponderosa pine.* Madroño 12:251-252.
Judging from chemical composition of turpentines, Apache pine should be considered an independent species from ponderosa pine.

856. Mirov, N. T.
1954. *Chemical composition of gum turpentines of pines of the United States and Canada.* J. Forest Products Res. Soc. 7(1):1-7.
Reviews work to inventory turpentines of the pines of the world.

857. Mirov, N. T., P. M. Iloff, Jr., and L. B. Gordon.
1954. *Composition of gum turpentines of pines. XVIII. A report on Pinus pungens, P. glabra, and P. teocote.* J. Am. Pharm. Assoc. Sci. Ed. 43(1):13-15.
Gives methods and results of oleoresin analysis as part of turpentine inventory studies.

858. Mirov, N. T., and P. M. Iloff, Jr.
1954. *Composition of gum turpentines of pines. XX. A report on Pinus chihuahuana from Durango, P. apacheca from Arizona, and P. monticola from northern Idaho.* J. Am. Pharm. Assoc. Sci. Ed. 43(6):378-381.
See item 857 above.

859. Mirov, N. T.
1954. *Composition of turpentines of Mexican pines.* Unasylva 8(4):167-173.
Summarizes studies on turpentine inventory studies by the California Forest and Range Experiment Station.

860. Mirov, N. T.
1954. *Studies of the chemical composition of turpentine of the genus Pinus in relation to taxonomy.* Eighth Int. Bot. Congr., Paris. p. 47-49.
Reports work done at Institute of Forest Genetics, Placerville, Calif., on application of chemical findings to problems of botany and tree breeding.

861. Mirov, N. T., and P. M. Iloff, Jr.
1955. *Composition of gum turpentine of pines. XXIV. A report on two asiatic pines, Pinus armandi and P. bungeana.* J. Am. Pharm. Assoc., Sci. Ed. 44(7):424-427.
Gives the results of chemical analysis of oleoresins.

862. Mirov, N. T., and P. M. Iloff, Jr.
1955. *Composition of gum turpentines of pines. XXIII. A report on three Mediterranean species, Pinus pinea (cultivated in California), P. halepensis (from Israel) and P. brutia (from Cyprus).* J. Am. Pharm. Assoc.,

Sci. Ed. 44(3):186-189.
See item 861 above.

863. Mirov, N. T.
1955. *Relationships between Pinus halepensis and other insignes pines of the Mediterranean region.* Bull. Res. Counc. of Israel. Dec. 1955, 5D(1):65-72.
On the basis of well established ecological and morphological differences and the differences in the chemical composition of their turpentines, *Pinus halepensis* and *P. brutia* should be considered distinct biological entities.

864. Mirov, N. T., and P. M. Iloff, Jr.
1956. *Composition of gum turpentines of pines. XXV. A report on two white pines Pinus koraiensis from Korea and P. peuce from Macedonia.* J. Am. Pharm. Assoc., Sci. Ed. 45(2):77-81.
Turpentines of both pines contained large amounts of diterpenes.

865. Mirov, N. T., and P. M. Iloff, Jr.
1956. *Composition of gum turpentines of pines, XXVI. A report on Pinus lawsoni and P. herrerai from Michoacan, Mexico. and P. ponderosa from the California coast.* J. Am. Pharm. Assoc., Sci. Ed. 45(3):153-156.
Turpentine of ponderosa pine from the Santa Cruz mountains had some characters found in that of Coulter pine.

866. Mirov, N. T., and P. M. Iloff, Jr.
1956. *Composition of gum turpentines of pines. XXVIII. A report on Pinus edulis from eastern Arizona, P. tropicalis from Cuba, and P. elliottii* var. *densa from Florida.* J. Am. Pharm. Assoc., Sci. Ed. 45(9):629-634.
A new chemical compound, never previously reported in any plant, was discovered in the turpentine of pinyon.

867. Mirov, N. T.
1956. *Composition of turpentines of lodgepole and jack pine hybrids.* Can. J. Bot. 34:443-457, illus.
Jack pine (bicyclic) turpentines dominated over lodgepole (monocyclic) turpentines in both artificial and natural hybrids.

868. Mirov, N. T., and P. M. Iloff, Jr.
1958. *Composition of gum turpentines of pines. XXIX. A report on Pinus ponderosa from five localities: central Idaho, central Montana, southeastern Wyoming, northwestern Nebraska, and central eastern Colorado.* J. Am. Pharm. Assoc., Sci. Ed., 47(6):404-409.
Results show that regardless of provenance, and despite the existence of several varieties, this species always contains large amounts of Δ^3-carene.

869. Mirov, N. T.
1958. *Composition of gum turpentines of pines XXX. A report on Pinus serotina, P. tenuifolia, and P. yunnanesis.* J. Am. Pharm. Assoc., Sci. Ed., 47:410-413.
The chemical components of the terpenes of each species are given with a summary of the findings presented in this and 29 previous papers.

870. Mirov, N. T.
1958. *The physiology of forest trees. Chapter 12. Distribution of components of turpentine among species of the genus Pinus.* The Roland Press, New York, p. 251-268.
Gives information on the specificity of turpentines, the stability and variability of turpentine composition within a species, and the distribution of terpenes within the genus.

871. Mirov, N. T.
1958. *Pinus oaxacana, a new species from Mexico.* Madroño 14(5):145-150.
Based on its morphological and biochemical features, a pine formerly identified as *Pinus pseudostrobus* Lindl. is designated a new species.

872. Mirov, N. T.
1959. *Chemistry in the service of silviculture.* Soc. Am. For. Proc. 1958:144-145.
Chemical methods may help detect variability among forest trees, recognize insect-resistant trees, tell hybrids from their parents, and possibly regulate flowering and seed production.

873. Mirov, N. T.
1960. *Biochemical geography of the genus Pinus.* Ninth Int. Bot. Congr. Proc. 1959:265.
Studies suggest that the area of origin of the genus was located on a land mass, now not existing, between North America and the northeastern part of Asia.

874. Mirov, N. T.
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875. Mirov, N. T.
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941. Atkinson, William A., and Dale O. Hall.
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942. Atkinson, William A., and Dale O. Hall.
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949. Brundage, M. R.
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951. Casamajor, P., and C. C. Wilson.
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960. Dell, John D., and Franklin R. Ward.
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964. Gordon, Donald T.
1956. *Slash disposal and seedbed preparation by tractor.* J. For. 54(11):771-773.
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965. Green, Lisle R.
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The trend in the Pacific Coast Douglas-fir region is toward reduced clearcut burning and greater utilization of forest debris.

966. Hall, Dale O., and Robert L. Neal.
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970. Hallin, William E.
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972. Hallin, William E.
1939. *Redwood logging costs in Mendocino County.*

U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 20, 21 p. Berkeley, Calif.
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973. Hallin, William E.
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974. Hasel, A. A.
1938. *Methods-of-cutting demonstration plots.* 3 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes a series of study plots and compares the results of three methods of cutting—salvage sanitation, modified Forest Service, and standard Forest Service.

975. Hasel, A. A.
1945. *The Blacks Mountain portable log loader.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 43, 8 p. Berkeley, Calif.
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977. Hasel, A. A.
1949. *Long-term silvicultural experiment on methods of cutting.* In *Proceedings of the Berkeley Symposium on Mathematical Statistics and Probability,* p. 477-479. Univ. of Berkeley Press, Berkeley.
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978. Hendee, John C., Harry E. Schimke, Ben S. Bryant, and James L. Murphy.
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At the end of the first year, the field test showed some differences between treated and untreated slash, but follow-up laboratory studies indicated that treatment had no significant value as an accelerator of decomposition.

979. Hopkins, W.
1957. *Watershed management considerations for sanitation-salvage logging in Southern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 121, 4 p. Berkeley, Calif.
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980. Keen, F. P.
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Ponderosa pine snags in southern Oregon and northeastern California deteriorated and fell very slowly at first and then rapidly after about 5 years except for trees of large diameter which remained standing for longer periods.

981. Kimmey, J. W.
1954. *How to determine when an area was logged.* J. For. 52(1):40.
Dates on 'snoose' cans, pore layers on conks, logging wounds, and annual rings on remaining trees aid in dating year of logging.

982. May, Richard H.
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983. May, Richard H., and Allan L. Hartong.
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From 28 measured plots, residue as a percent of timber products output was estimated at 2 percent in the Pine Region and 17 percent in the Redwood Region, for the sawlog portion of the tree by board measure.

984. McDonald, Philip M.
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The 90-foot opening indicated the highest production rate, for both felling (including limbing and bucking) and skidding, the 60-foot opening the lowest, for studied diameters of 30, 60, and 90 feet.

985. McDonald, Philip M., and Harry E. Schimke.
1966. *A broadcast burn in second-growth clear cuttings in the north central Sierra Nevada.* U.S. Forest Serv. Res. Note PSW-99, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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986. McDonald, Philip M.
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987. McDonald, Philip M., William A. Atkinson, and Dale O. Hall. J. For. 67(2):109-113, illus.
1969. *Logging costs and cutting methods in young-growth ponderosa pine in California.* J. For. 67(2):109-113, illus.
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988. McDonald, Philip M., and Raymond V. Whiteley.
1972. *Logging a roadside stand to protect scenic values.* J. For. 70(2):80-83, illus.
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989. McDonald, Philip M.
1972. *Logging production rates in young-growth, mixed-conifer stands in north central California.* USDA Forest Serv. Res. Paper PSW-86, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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990. McDonald, Philip M.
1973. *Cutting a young-growth, mixed-conifer stand tc California Forest Practice Act standards.* USDA Forest Serv. Res. Paper PSW-89, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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993. Murphy, James L., Leo J. Fritschen, and Owen P. Cramer.
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994. Orr, William J., and John D. Dell.
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995. Person, H. L.
1935. *Redwood uphill tractor logging.* West Coast Lumberman 62(10):24-25.
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996. Person, H. L.
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997. Person, H. L.
1937. *Comparative costs for slackline, highlead and tractor yarding.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 15, 5 p. Berkeley, Calif.
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998. Person, H. L.
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See item 996 above.

999. Person, H. L.
1938. *Selective logging in the redwood region.* Timberman 39(6):32.
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1000. Rice, Raymond M., and James R. Wallis.
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1001. Schimke, Harry E., and Ronald H. Dougherty.
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1002. Schimke, Harry E., and Ronald H. Dougherty.
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1003. Schimke, Harry E., and Ronald H. Dougherty.
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1004. Stahelin, Rudolf, and W. Hallin.
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1005. Sundahl, William E.
1966. *Slash and litter weight after clearcut logging in two young-growth timber stands.* U.S. Forest Serv. Res. Note PSW-124, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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1007. Tevis, L., Jr.
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1008. Tevis, L., Jr.
1956. *Responses of small mammal populations to logging of Douglas-fir.* J. Mamm. 37(2):189-196.
See item 1006 above.

1009. Wagener, Willis W., and Harold R. Offord.
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Breakdown of unburned logging slash occurred at a much slower rate than has been reported in other forest regions of the United States.

1010. Wallis, James R.
1963. *Logging for water quality in northern California.* U.S. Forest Serv. Res. Note PSW-23, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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1011. Wieslander, A. E.
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1012. Wilson, R. C.
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1013. Wilson, R. C.
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Freezing of the bare soil caused the surface to become and remain wet and greatly increased evaporation.

1015. Anderson, H. W.
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1016. Boe, Kenneth N.
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1017. Colwell, Wilmer L., Jr.
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1021. Fons, W. L., H. D. Bruce, and A. McMasters.
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1022. Fowells, H. A.
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1023. Gordon, Donald T.
1968. *Tree shadow patterns and illumination measurements within clearcut strips and irregular openings in a true fir forest.* U.S. Forest Serv. Res. Note PSW-172, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Daily progression of shadows cast by trees into stand openings is illustrated by means of vertical aerial photographs made at 2-hour intervals from 7 a.m. to 5 p.m.

1024. Gordon, Donald T.
1973. *Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings.* USDA Forest Serv. Res. Paper PSW-90, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

In "normal" years, bark beetles killed more trees than did wind damage, but two severe wind storms caused large amounts of entirely different kinds of tree damage.

1025. Halverson, H. G., and J. L. Smith.
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1027. Krugman, Stanley L.
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1972. *Influence of climate and topography on oxidant air pollution concentrations that damage conifer forests in southern California.* In *Effects of air pollutants on forest trees.* VII Int. Symp. of Forest Fume Damage Experts. Forstliche Bundesversuchanstalt, Wien. Vol. I, p. 585-608, illus.
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Describes the design and construction of a transmitter, usable with portable radio or field telephone circuits for synchronizing multi-theodolite observation of pilot balloons.

1039. Muller, Robert A.
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1970. *Snow bending of sugar and ponderosa pine seedlings . . . injury not permanent.* USDA Forest Serv. Res. Note PSW-225, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Seedlings with stems bent by heavy snow loads were photographed the next summer and 10 years later, and showed complete recovery, with no permanent stem crook.

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1042. Powers, Robert F., and William W. Oliver.
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1043. Ratliff, Raymond D., and Jack N. Reppert.
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1045. Reimann, Lyle F., and Everett L. Hamilton.
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1046. Reimann, Lyle F.
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1047. Reimann, Lyle F.
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1048. Rice, Raymond M.
1959. *Snow management research in High Sierra range.* J. Range Manage. 12(1):13-16, illus.
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1049. Santeford, N. S., and J. L. Smith.
1974. *Advanced concepts and techniques in the study of snow and ice resources.* In *Advanced concepts and techniques in the study of snow and ice resources,* p. 76-89. Natl. Acad. of Sci. Washington, D.C.
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1050. Schubert, Gilbert H.
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Immature sugar pine cones were injured by freezing during late spring of the second year when the temperature dropped below 20° F.

1051. Schubert, Gilbert H.
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1052. Smith, R. S., Jr., R. F. Scharpf, and E. R. Schneegas.
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1053. Stark, N. B.
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1056. Storey, H. C.
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1057. Storey, H. C., and H. G. Wilm.
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1960. *A comment on cold susceptibility of ponderosa and Jeffrey pines.* Madroño 15:217-219.
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1062. Wert, Steven L., Paul R. Miller, and Robert N. Larsh.
1970. *Color photos detect smog injury to forest trees.* J. For. 68(9):536-539, illus.
A scale of 1:8000 was best for detecting smog injury to trees, whereas a scale of 1:1584 was best for evaluating affected trees.

1063. West, Allan J.
1959. *Snow evaporation and condensation.* Proc. 27th

Annu. West. Snow Conf. 1959:68-74.
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1064. West, Allan J.
1961. *Cold air drainage in forest openings.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 180, 6 p., illus. Berkeley, Calif.
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1962. *Snow evaporation from a forested watershed in the central Sierra Nevada.* J. For. 60(7):481-484, illus.
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1066. Williams, Carroll B., Jr., and C. T. Dyrness.
1967. *Some characteristics of forest floors and soils under true fir-hemlock stands in the Cascades of Oregon and Washington.* U.S. Forest Serv. Res. Paper PNW-37, 19 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.
Measurements in 46 plots showed an average forest floor depth of 1.8 inches and an average weight of 56,754 pounds per acre with forest floor nutrient content showing little variation among forest types.

Weed and Brush Control

1067. Abell, C. A.
1938. *Stripping brushfields for planting in California* J. Wildlife Manage. 2(4):182-183.
The Plumas brush stripper has proved effective in the preparation of planting sites by efficiently clearing dense brush.

1068. Baron, Frank J., N. Stark, and Gilbert H. Schubert.
1964. *Effects of season and rate of application of 2,4-D and 2,4,5-T on pine seedlings and mountain whitethorn in California.* J. For. 62(7):472-474.
Eight-year-old sugar pine reproduction, within clumps of mountain whitethorn, exhibited accelerated height growth for 2 years after certain foliar applications of herbicides, although season and rate of application strongly influenced the results.

1069. Bentley, Jay R., Lisle R. Green, and A. B. Evanko.
1966. *Principles and techniques in converting native chaparral to stable grassland in California.* Proc. 10th Int. Grassland Congr. 1966:55-59.
Grass sown immediately after chaparral has burned can alter natural succession by competing with shrub seedlings for soil moisture, but this effect is temporary unless shrubs are also controlled with herbicides.

1070. Bentley, Jay R.
1967. *Brushfield reclamation in California.* Symp. on Herbicides and Vegetation Manage. in Forests, Ranges, and Non-crop land Proc.:186-195. Oregon State Univ., Corvallis, Oreg.
Brushfields on the Sierra Nevada and Cascade Ranges are cleared for pine plantations by bulldozing, prescribed burning, or wildfire.

1071. Bentley, Jay R.
1967. *Conversion of chaparral areas to grassland . . . techniques used in California.* U.S. Dep. Agric. Handb. 328, 33 p., illus. Forest Serv., U.S. Dep. Agric., Washington, D.C.
The brush conversion process consists of five distinct steps which must be taken at the right time and in the right way.

1072. Bentley, Jay R., C. Eugene Conrad, and Harry E. Schimke.
1971. *Burning trials in shrubby vegetation desiccated with herbicides.* USDA Forest Serv. Res. Note PSW-241, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Intense fires burned in all treated plots, but undesiccated large stems were not consumed except where desiccation was allowed to progress for an additional year.

1073. Bentley, Jay R., Stanley B. Carpenter, and David A. Blakeman.
1971. *Early brush control promotes growth of ponderosa pine planted on bulldozed site.* USDA Forest Serv. Res. Note PSW-238, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
This early control also promises to reduce the amount of hazardous brush fuel in the plantation for an indefinite period.

1074. Blanchard, Robert K.
1947. *Killing brush with 2,4-D.* Fire Control Notes 8(2):13-17.
Describes the compound 2,4-D, its properties, toxicity, handling and effectiveness.

1075. Boe, Kenneth N.
1971. *Growth of released redwood crop seedlings on the Redwood Experimental Forest.* USDA Forest Serv. Res. Note PSW-229, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The brief acceleration in growth did not enable the released seedlings to surpass the competition much better than the controls.

1076. Bruce, H. D.
1936. *Summary of stump eradication experiments.* 39 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Gives the results of treating sprouting stumps with several chemicals, under various conditions of concentration, location, season, and mode of preparation.

1077. Bruce, H. D.
1938. *Experiments with chemicals for control of vegetation.* 7 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes methods of killing sprouting stumps, eradicating dense perennial shrubs such as bear clover, and sterilizing soil against annual vegetation.

1078. Bruce, H. D.
1938. *Instructions in the use of chemicals for sterilizing the soil.* 7 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Advises on the best methods of handling arsenic in sterilization treatments.

1079. Bruce, H. D.
1939. *Chemical killing of sprouting stumps.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 23, 4 p. Berkeley, Calif.
Describes a method of eradicating stumps with ammonium sulfamate that is both certain and economically practical.

1080. Bruce, H. D.
1939. *The role of chemicals in firebreak maintenance.* Utah Juniper 10:12-19.
Sprouting stumps can be cleared by the application of chlorate to the root crown and soil sterilization can be accomplished through the use of white arsenic trioxide.

1081. Bruce, H. D.
1939. *Sterilizing soil with chemicals for firebreak maintenance.* Fire Control Notes 3(1):17-21.
Describes the successful use of arsenic trioxide to increase the permanence of backfiring strips by sterilizing the soil.

1082. Bruce, H. D.
1940. *White arsenic to sterilize soil.* Pacific Rural Press 140(13):401.
Describes the properties and uses of arsenic trioxide to eradicate vegetation.

1083. Bruce, H. D.
1942. *Sterilizing soil with chemicals.* 4 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes the use of white arsenic trioxide and borax to eradicate vegetation.

1084. Buttery, R. F., J. R. Bentley, and T. R. Plumb, Jr.
1959. *Season of burning affects follow-up chemical control of sprouting chamise.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 154, 11 p., illus.
Late spring burning is a good practice which gives the best chance for control of sprouts with one broadcast chemical application.

1085. Carpenter, Stanley B.
1966. *Controlling cull ohia trees by injecting herbicides.* U.S. Forest Serv. Res. Note PSW-125, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
An injection of undiluted 2,4,5-T ester killed trees less than 6 inches in diameter but was less effective on larger trees, effectiveness subject to time of season.

1086. Carpenter, Stanley B.
1966. *Herbicides for site preparation—broadcast spray by mist blower tested against understory in Hawaii rain forest.* U.S. Forest Serv. Res. Note PSW-115, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes the results of two studies started in 1964.

1087. Carpenter, Stanley B.
1967. *Brush-killer stimulates adventitious rooting of tropical ash in Hawaii.* J. For. 65(6):421.
Brushkiller (2,4-D and 2,4,5-T) applied in mist form with a turbine blower caused the development of adventitious roots on the stems of 77-year-old tropical ash.

1088. Conrad, E. Eugene, and Charles A. Graham.
1967. *Brush control—an unfinished job.* J. Range Manage. 20(2):84-88, illus.
A brief picture essay shows how brush control is achieved by crushing and burning, and how lack of follow-up can nullify initial gains.

1089. Cornelius, Donald R., and Charles A. Graham.
1951. *Selective herbicides for improving California forest ranges.* J. Range Manage. 4(2):95-100.

Reports results of preliminary tests of 2,4-D and 2,4,5-T for weed and brush control.

1090. Cornelius, Donald R., and Charles A. Graham.
1953. *Chemical control of buttercup in mountain meadows.* J. For. 51(9):631-634.
Results of experiments with 2,4-D herbicide formulations, carriers, rates and times of application.

1091. Cornelius, Donald R., and Charles A. Graham.
1958. *Sagebrush control with 2,4-D.* J. Range Manage. 11:122-125.
Butyl ester of 2,4-D at 2 pounds acid equivalent per acre gave best control, however low volatile esters should be used if susceptible crops grow nearby.

1092. Crafts, A. S., N. D. Bruce, and R. H. Raynor.
1941. *Plot tests with chemical soil sterilants in California.* U.S. Forest Serv. Calif. Agric. Exp. Stn. Bull. 648, 25 p. Berkeley, Calif.
Analyzes experiments on five commercially available chemicals for use on firebreaks.

1093. Crafts, A. S., and C. C. Buck.
1954. *Herbicidal properties of arsenic trioxide.* Univ of Calif. Agric. Exp. Stn. Bull. 739, 28 p. Berkeley, Calif.
Presents findings of greenhouse and field experiments and gives recommendations for use as a weed preventative.

1094. Curry, John R., and G. J. Ikenberry.
1934. *Instructions in the use of sodium arsenite in killing sprouting stumps on firebreaks.* 8 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Gives instructions on the proper methods of preparation, application, and storage of sodium arsenite.

1095. Curry, John R., and H. D. Bruce.
1935. *Instructions in the use of diesel oil in killing sprouting stumps in California firebreaks.* 4 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Recommends using diesel oil as a safe alternative to sodium arsenite and gives directions for its use in killing stumps.

1096. Estes, Kenneth M., and David A. Blakeman.
1970. *Foliar spraying of sprouting Tanoak plants best in late summer.* USDA Forest Serv. Res. Note PSW-207, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Foliar applications—by either backpump sprayer or backpack mistblower—gave best control in August and September, with 2,4,5-T alone or a 1-1 mix with 2,4-D being equally effective.

1097. Fenner, Ralph L., Keith Arnold, L. T. Burcham, and R. F. Grah.
1951. *Use of fire in land clearing.* Calif. Agric. 5(3-7):9-15.
Five articles about controlled burning of an area are reprinted and bound in one cover.

1098. Fenner, Ralph L., R. K. Arnold, and C. C. Buck.
1955. *Area ignition for brush burning.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 10, 10 p., illus. Berkeley, Calif.
Outlines methods and precautions for safer, more effective controlled burns in land clearing and describes brush-smashing technique for fuel preparation before firing.

1099. Goodin, J. R., L. R. Green, and V. W. Brown.
1966. *Picloram . . . a promising new herbicide for control of woody plants.* Calif. Agric. 20(2):10-12.
Reports on experiments in which picloram control data from several environmental conditions and vegetation types in southern California were compared.

1100. Graham, Charles A.
1953. *A practical way to evaluate spray distribution.* J. Range Manage. 6(4):255-259.
Spray coverage variations can be detected by use of paper sensitized to minute amounts of ferric chloride added to the spray emulsion.

1101. Graham, Charles A.
1958. *Killing brush sprouts on open range land in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 136, 5 p. Berkeley, Calif.
Chemical control following controlled burning was most effective and economical if done for 3 years.

1102. Graham, Charles A., and Jay R. Bentley.
1975. *Portable tripod-mounted boom sprayer for applying herbicides on tall shrubs.* USDA Forest Serv. Res. Note PSW-302, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A pneumatic-powered sprayer mounted on a counterbalanced 25-foot boom can spray several hundred plots in brush with a canopy up to 15 feet in height.

1103. Green, Lisle R., and Charles A. Graham.
1957. *Observations on growth and control of tarweed.* U.S. Forest Serv. Calif. Forest and Range Exp.

Stn. Res. Note 130, 8 p., illus. Berkeley, Calif.
A method used on annual-type foothill ranges which proved an effective control was mowing in August and broadcast spraying a 50-50 mixture of a low volatile ester of 2,4-D and 2,4,5-T.

1104. Green, Lisle R., Verdie E. White, and Timothy R. Plumb.
1964. *Some brush conversion costs on southern California fuel-breaks.* U.S. Forest Serv. Fuel-break Rep. 12, 18 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Types of jobs considered in this cost estimation include hand clearing, bulldozer clearing, smashing and disking, broadcast spraying by tractor boom and helicopter, hand spraying of individual plants, and drill seeding.

1105. Green, Lisle R., and Joe R. Goodin.
1965. *A trial of picloram for controlling chaparral species in southern California.* Twentieth West. Weed Contr. Conf. Proc. 20:28-30.
A new herbicide, picloram, appears to approach but not exceed brushkiller's (2,4-D and 2,4,5-T) effectiveness on many chaparral species.

1106. Green, Lisle R., Joe R. Goodin, and Timothy R. Plumb.
1966. *Picloram herbicide for killing chaparral species . . . a preliminary rating.* U.S. Forest Serv. Res. Note PSW-122, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Ability of picloram spray solution and pellets to destroy woody vegetation proved to be about the same to slightly better than brushkiller's (2,4-D and 2,4,5-T).

1107. Ikenberry, G. J., H. D. Bruce, and J. R. Curry.
1938. *Experiments with chemicals in killing vegetation on firebreaks.* J. For. 36(5):507-515.
Various chemicals, including chlorates, arsenic compounds, and petroleum oil were used to kill sprouting stumps and to sterilize soils.

1108. Kirk, B. M.
1941. *The fall plantations of the Burney Spring experiment in brush-field reforestation, 1937.* 21 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Three brush eradication treatments were compared and a test of forest planting methods was made.

1109. Klinger, Keith A., and Carl C. Wilson.
1968. *What are we going to do about the brush in southern California?* Fire Control Notes 29(1):3-6, 16, illus.
Suggests the development of fuel-break systems in which the chaparral is reduced or removed in strategic strips or areas, and converted to grass or other low fuel volume, slow burning plants.

1110. Krammes, Jay S., and David B. Willets.
1964. *Effect of 2,4-D and 2,4,5-T on water quality after a spraying treatment.* U.S. Forest Serv. Res. Note PSW-52, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Removing and spraying the vegetation at the bottom of Monroe Canyon resulted in an increase in the usable water without noticeable stream pollution due to pesticides.

1111. McDonald, Philip M.
1966. *Brushfield reclamation—second-year results from a study of reforestation with ponderosa pine are encouraging.* U.S. Forest Serv. Res. Note PSW-118, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
There were no seedling survival or height differences among the site preparation treatments, but a significant difference appeared between survival of planted seedlings and those originating from the rangeland drill seeding.

1112. Neuns, Alva G., and Albert Simpson.
1951. *The use of 2,4-D and 2,4,5-T for brush control on California forest roads and trails.* 27 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Contains instructions and practical information on the use of this herbicide for the control of brush regrowth.

1113. Neuns, Alva G.
1952. *Woody plant control along roads in Shasta National Forest.* Down to Earth 8(1):14-15.
Describes a successful 1949 attempt by the Forest Service to control roadside brush with 2,4-D and 2,4,5-T.

1114. Offord, H. R.
1957. *Brush control on forest lands.* Ninth Annu. Weed Conf. Proc. 1957:72-75.
Summarizes the objectives, methods, and problems in controlling brush with chemicals in California.

1115. Offord, H. R.
1959. *Phytocides in silviculture.* Soc. Am. For. Proc. 1958:175-176.
Reviews the chief factors that affect the successful use of selective weed killers for controlling unwanted vegetation on forest land.

1116. Patric, J. N.
1959. *Sulfur dioxide as a defoliant of chaparral plants.* J. For. 57(6):437-438, illus.

Sulfur dioxide gas proved to be an effective defoliant of several chaparral plants.

1117. Plumb, Timothy R., and J. R. Bentley.
1960. *Rate of broadcast 2,4-D spraying on second-year chamise sprouts.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 163, 7 p., illus. Berkeley, Calif.

Describes the optimum application rates for controlling 2-year old chamise sprouts in a burned-over area.

1118. Plumb, Timothy R.
1961. *Sprouting of chaparral by December after a wildfire in July.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 57, 12 p., illus. Berkeley, Calif.

By December the dominant species, chamise and scrub oak, had produced only a limited volume of foliage.

1119. Plumb, Timothy R.
1962. *Four tests of broadcast spraying in killing first-year chamise sprouts.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 200, 6 p., illus. Berkeley, Calif.

One pound acid equivalent was found inadequate, 2 was borderline, and 4 was almost as effective as 8, however varying the amount of oil in the emulsion, substituting 2,4,5-T for part of the 2,4-D, and changing the size of the nozzle did not greatly affect the degree of kill obtained.

1120. Plumb, Timothy R.
1962. *Three years of broadcast spraying chamise sprouts in southern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 197, 9 p., illus. Berkeley, Calif.

Reports the effects of rate, volume, and timing of chemical application, the influence of plant coverage, chemical formulation, and annual growing conditions and the cost of of spraying.

1121. Plumb, Timothy R., J. R. Bentley, and V. E. White.
1963. *Chemical control of brush regrowth on fuel-breaks.* Fuel-break Rep. No. 11, 42 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

This paper describes chemical control methods, application costs, and spray recommendations for plant control on fuel-breaks, and gives an appendix of some useful tables.

1122. Plumb, Timothy R.
1963. *Delayed sprouting of scrub oak after a fire.* U.S. Forest Serv. Note PSW-1, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Low soil moisture is believed to be the primary cause of this dormancy which complicates herbicidal control on brush conversion areas.

1123. Plumb, Timothy R., L. R. Green, and V. E. White.
1966. *Spray pattern and drift from two types of nozzles used for helicopter spraying.* Weeds 14(2):114-116, illus.

A whirljet nozzle produced less drift than a flat, fan-type nozzle.

1124. Plumb, Timothy R.
1967. *Brushkiller to control scrub oak sprouts . . . combinations of broadcast and individual plant applications tested.* U.S. Forest Serv. Res. Note PSW-146, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A tested 50-50 combination of 2,4-D and 2,4,5-T in water-oil emulsion needed three successive applications to obtain satisfactory control.

1125. Plumb, Timothy R.
1968. *Control of brush regrowth in southern California with Tordon and phenoxy herbicides.* Down to Earth 24(3):19-22, illus.

Compares effectiveness of both herbicides when applied to individual plants and when used in broadcast treatment.

1126. Plumb, Timothy R.
1969. *Control of chamise regrowth with phenoxy herbicides . . . affected by sprout age, date of application.* USDA Forest Serv. Res. Note PSW-192, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The beginning of May was found to be the best time to spray older sprouts and late May was best for the first-year sprouts.

1127. Plumb, Timothy R.
1971. *Broadcast applications of herbicides to control scrub oak regrowth.* USDA Forest Serv. Res. Note PSW-261, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Effectiveness appeared to be somewhat related to plant height, but plant size in terms of diameter or volume had little or no apparent relationship except for small or large plants.

1128. Quick, C. R., and W. S. Burrill.
1956. *Research Progress Report. Additional results from herbicide tests on ribes in California.* Res. Comm. West. Weed Control Conf. 1956:41-42.
Summarizes results in 1955 from field tests of chlorinated phenoxy herbicides and other chemical weedkillers.

1129. Quick, C. R.
1958. *Herbicide tests on ribes continue in California.* West. Weed Control Conf., Res. Comm. Progress Report 1958:43-44.
Summarizes tests of herbicides for the years 1956 and 1957.

1130. Reed, Merton J., and Jay R. Bentley.
1961. *Conversion from brush to grass for multiple land use.* Soc. Am. For. Proc. 1960:147-149, illus.
The key to permanent conversion is suitable chemical control of brush regrowth, careful site selection on moderate slopes with stable, productive soil, safe, clean brush removal, positive grass establishment by seeding or assured natural establishment, and protection from grazing the first season.

1131. Roy, Douglass F.
1956. *Killing tanoak in northwestern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 106, 9 p., illus. Berkeley, Calif.
Large trees showed delayed effects from frilling but will eventually die; small trees were killed with basal hormone sprays, and sprouts were eliminated by 2,4-D or 2,4,5-T.

1132. Schimke, Harry E., Lisle R. Green, and Danny Heavilin.
1970. *Perennial grasses reduce woody plant seedlings . . . on mixed conifer fuel-break.* USDA Forest Serv. Res. Note PSW-203, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Grasses reduced the number of seedlings by a factor of 8, reduced height by 50 percent, and annual plant ground cover by one-third.

1133. Schubert, Gilbert H.
1950. *Control of sprouting of tanoak and madrone stumps.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 74, 2 p. Berkeley, Calif.
Treatment of stumps with a one-percent water solution of the isopropyl ester of 2,4-D was an effective means of control.

1134. Schubert, Gilbert H.
1955. *Recent trials with 2,4-D and 2,4,5-T to kill brush in the Sierra Nevada in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 102, 7 p. Berkeley, Calif.
Describes the results of several trials and gives recommendations on how to kill mountain whitethorn, Sierra evergreen-chinkapin, bearmat, littleleaf ceanothus, and green leaf manzanita.

1135. Schubert, Gilbert H.
1962. *Chemicals for brush control in California reforestation.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 73, 14 p. Berkeley, Calif.
Summarizes findings from experimental trials with selective herbicides and recommends formulations and amounts to apply.

1136. Wagle, R. F., and Clive M. Countryman.
1963. *Spray penetration in scruboak with helicopter application.* J. Range Manage. 16(6):333-335, illus.
Tests conducted during Operation Firestop in 1954 showed that spray penetration of heavy brush was aided considerably by the downdraft of the helicopter rotor.

1137. Walters, Gerald A., and William S. Null.
1970. *Controlling firetree in Hawaii by injection of Tordon 22K.* USDA Forest Serv. Res. Note PSW-217, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Injections squirted into notches cut with machetes gave rapid and complete canopy kill and 99 percent control of sprouting.

1138. Walters, Gerald A.
1973. *Tordon 212 ineffective in killing firetree in Hawaii.* USDA Forest Serv. Res. Note PSW-284, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
No combination of herbicide, notch interval, and treatment season tested was effective in controlling firetree.

1139. Webb, Warren L.
1968. *Desiccation of woody stems . . . influenced by connected live tissues.* USDA Forest Serv. Res. Note PSW-186, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

In an exploratory study, the desiccation rate decreased markedly if dead stems were connected to a live root system.

FOREST INSECTS AND DISEASES

Forest Insects

1140. Bedard, William D.
1965. *The biology of Tomicobia tibialis (Hymenoptera: Pteromalidae) parasitizing Ips confusus (Coleoptera: Scolytidae) in California.* Contrib. Boyce Thompson Inst. 23(4):77-81, illus.
Describes *T. tibialis,* a solitary, internal parasite which is attracted to logs freshly attacked by *I. confusus.*

1141. Bedard, William D.
1966. *A ground phloem medium for rearing immature bark beetles (Scolytidae).* Annu. Entomol. Soc. Am. 59(5):931-938, illus.
A ground phloem medium, developed to rear the California five-spined Ips, from egg to adult, is also applicable to seven other scolytids.

1142. Bedard, William D.
1966. *High temperature mortality of the sugar-pine cone beetle, Conophthorus lambertianae Hopkins (Coleoptera: Scolytidae).* Can. Entomol. 98(2):152-157, illus.
Concludes that broods within detached cones in sunny places are killed by high temperatures.

1143. Bedard, William D.
1966. *Variation in capacity of Ips confusus to reach attractive hosts.* Proc. N.A.T.O. and N.S.F. Symp.:137-142. Pergamon Press, Oxford.
Experimentally examines some assumptions underlying a described performance test to measure the capacity of adults to reach hosts.

1144. Bedard, William D.
1968. *Additions to the knowledge of the biology of Conophthorus lambertianae Hopkins (Coleoptera: Scolytidae).* The Pan-Pacific Entomol. 44(1):7-17, illus.
New information on the biology of this pest leads to the possibilities of control.

1145. Bedard, William D.
1968. *The sugar-pine cone beetle.* Forest Pest Leafl. 112, 6 p., illus.
This pest of sugar pine in California and Oregon has infestations characterized by killed cones and mined twig tips.

1146. Bedard, William D., and Lloyd E. Browne.
1969. *A delivery-trapping system for evaluating insect chemical attractants in nature.* J. Econ. Entomol. 62(5):1202-1203, illus.
An air pressure tank was adapted to deliver a continuous flow of air which carries the pheromones off substrates into ambient air.

1147. Bedard, William D., and others.
1969. *Western pine beetle: field response to its sex pheromone and synergistic host terpene, myrcene.* Science 164:1284-1285.
Myrcene, a monoterpene, enhances the attractiveness of brevicomin, a sex pheromone, to the western pine beetle.

1148. Bedard, William D., and D. L. Wood.
1974. *Bark beetles—the western pine beetle.* In *Pheromones,* p. 441-461, illus. Martin C. Birch, ed. North-Holland Publ. Co., Amsterdam.
Preliminary results of a large-scale evaluation of the efficacy of attractant pheromones in the suppression and survey of this beetle have been analyzed.

1149. Berryman, A. A., C. J. DeMars, Jr., and R. W. Stark.
1970. *Section 4. The development of sampling methods for "within-tree" populations of the western pine beetle.* In *Studies on the population dynamics of western pine beetle, Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae).* p. 33-36, illus. Univ. Calif. Div. Agric. Sci., Berkeley, Calif.
Summarizes a study to develop sampling techniques for all stages of the beetle so as to have a basis for adequate estimation of mortality factors.

1150. Bohart, G. E., and T. W. Koerber.
1972. *Insect and seed production.* In *Seed biology.* T. T. Kozlowski, ed. Vol. III, p. 1-53, illus. Academic Press, Inc., New York.
Includes insect pollination and harmful impact of insects on seeds and seed production.

1151. Boone, R. Sidney.
1965. *Dry-wood termite attacks in a 55-year-old display of Hawaii-grown wood.* Pacific Sci. 20(4):524-527.
Of 79 wood samples, including 79 species, 54 samples were not attacked.

1152. Buffam, Paul E., and V. M. Carolin, Jr.
1966. *Determining trends in western spruce budworm*

egg populations. J. Econ. Entomol. 59(6):1442-1444.
Four year's data from 10 plots in southern Oregon and northern California indicate that trends can be obtained with one year's sampling by using 'old' egg masses to represent the previous year's 'new' egg masses.

1153. Callaham, Robert Z.
1955. *Sapwood moisture associated with galleries of Dendroctonus valens.* J. For. 53:916-917.
A preliminary study concluded drying of the sapwood directly beneath the beetle's galleries contributed to the ultimate death of the tree.

1154. Callaham, Robert Z., and Moshe Shifrine.
1960. *The yeasts associated with bark beetles.* Forest Sci. 6(2):146-154.
Summarizes available information on the association between bark beetles, yeasts, and the trees which serve as their hosts and concludes that well designed studies are needed to gain an understanding of the interrelationships between bark beetles and their yeast flora.

1155. Clements, V. A.
1953. *Possible means of reducing mountain pine beetle attacks in young sugar pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 89, 5 p. Berkeley, Calif.
Recommends removal of especially susceptible trees or reducing stand density to alleviate impact of this insect.

1156. DeMars, Clarence J., Jr.
1963. *A comparison of radiograph analysis and bark dissection in estimating numbers of western pine beetle.* Can. Entomol. 95(10):1112-1116, illus.
Counts of images appearing on X-ray plates is a satisfactory substitute for the slower actual count made by carefully shaving away the bark.

1157. DeMars, Clarence J., Jr.
1964. *Predicting insect-caused damage to Douglas-fir seed from samples of young cones.* U.S. Forest Serv. Res. Note PSW-40, 7 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The percent of seed destroyed by *Barbara colfaxiana, Dioryctria abietella, Megastigmus spermotrophus,* and *Contarinia oregonensis* was estimated from samples of cones which were examined by axial-slice and complete dissection.

1158. DeMars, Clarence J., Jr., A. A. Berryman, D. L. Dahlsten, I. S. Otvos and R. W. Stark.
1970. *Section 9. Spatial and temporal variations in the distribution of western pine beetle, its parasites and predators, and woodpecker activity in infested trees.* In *Studies on the population dynamics of western pine beetle, Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae).* p. 80-101, illus. Univ. Calif. Div. Agric. Sci., Berkeley, Calif.
Reports measurement of the abundance of western pine beetle predators, parasites, and woodpecker activity over space (tree stem) and time (generation).

1159. DeMars, Clarence J., Jr.
1970. *Section 6. Frequency distributions, data transformations, and analysis of variations used in determining optimum sample size and effort for broods of western pine beetle.* In *Studies on the population dynamics of western pine beetle, Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae).* p. 42-65, illus. Univ. Calif. Div. Agric. Sci., Berkeley, Calif.
Summarizes results of five studies in statistical analysis in the quantitative investigation of insect populations.

1160. DeMars, Clarence J., Jr., D. L. Dahlsten, and R. W. Stark.
1970. *Survivorship curves for eight generations of the western pine beetle in California, 1962-1965, and a preliminary life table.* In *Studies on the population dynamics of western pine beetle, dendroctonus brevicomis LeConte (Coleoptera: Scolytidae).* p. 134-146, illus. Univ. Calif. Div. Agric. Sci., Berkeley, Calif.
Predictions based on preliminary life tables and survivorship curves should be considered speculative.

1161. Eaton, Charles B., and R. L. Lyon.
1955. *Arhopalus products (Lec.), a borer in new buildings.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 11, 11 p., illus. Berkeley, Calif.
Summarizes available information on this pest, which sometimes emerges from infested lumber in new buildings, and gives suggestions on how to alleviate the problem of infestation.

1162. Eaton, Charles B.
1955. *The Saratoga Spittlebug.* U.S. Dep. Agric. Forest Pest Leafl. 3, 4 p., illus.
Describes a pest particularly destructive to pine plantations of the Lake States.

1163. Eaton, Charles B.
1956. *Jeffrey pine beetle.* U.S. Dep. Agric. Forest Pest Leafl. 11, 7 p., illus.
Tells how to recognize the insect and its damage, outlines life history and habits, explains preventive control through selective logging and methods of applied control.

1164. Eaton, Charles B., and G. R. Struble.
1957. *The Douglas-fir tussock moth (Lepidoptera: Liparidae) in California.* Pan-Pacific Entomol. 33(3):105-108.
The Douglas-fir tussock moth, which heretofore has been erroneously identified as Oslar's tussock moth, is a potentially serious pest in California fir forests.

1165. Eaton, Charles B.
1959. *Insect-caused mortality in relation to methods of cutting in ponderosa pine on the Blacks Mountain Experimental Forest.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 43, 33 p., illus. Berkeley, Calif.
Contains the results of a 16-year study and summarizes data on volume and percent of stand killed annually for five systems of cutting and control.

1166. Eaton, Charles B.
1959. *Observations on the survival of Arhopalus productus (Lec.) larvae in Douglas-fir lumber (Coleoptera: Cerambycidae).* Pan-Pacific Entomol. 35(2):114-116.
Experiments show that as the wood dries out the larvae die from desiccation, which suggests that insect damage to lumber is limited by the wood's moisture content.

1167. Eaton, Charles B., and J. S. Yuill.
1960. *Gouty pitch midge.* U.S. Dep. Agric. Forest Pest Leafl. 46, 8 p., illus.
Describes the life history, habits, and control of a small itonidid fly which attacks the new shoots of hard pines and whose larvae deform and kill the new shoots of pines.

1168. Eaton, Charles B.
1962. *Entomological considerations in the economics of forest pest control.* J. For. 60(5):309-311.
Stresses the importance of biological data in considering insect control approaches and costs, particularly specific identification and origin of pests, differences between species, and level of infestation.

1169. Eaton, Charles B., and Rodriguez R. Lara.
1967. *California pine engraver, Ips (integer) plastographus (LeConte).* In *Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico.* A. G. Davidson, and R. M. Prentice, eds. Can. Dep. For. and Rural Dev. Publ. 1180, p. 25-26.

1170. Eaton, Charles B., and Rodriguez R. Lara.
1967. *Red turpentine beetle, Dendroctonus valens LeConte.* In *Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico.* A. G. Davidson and R. M. Prentice, eds. Can. Dep. For. and Rural Dev. Publ. 1180, p. 21-24.
Summarizes information on the distribution, hosts, and life history of this insect and briefly outlines suggested control measures.

1171. Eaton, Charles B., and R. R. LeJeune.
1967. *Western pine beetle, Dendroctonus brevicomis LeConte.* In *Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico.* A. G. Davidson and R. M. Prentice, eds. Can. Dep. For. and Rural Dev. Publ. 1180, p. 89-91.
Summarizes information on the distribution, hosts, and life history of this insect and briefly outlines suggested control measures.

1172. Ferrell, George T.
1971. *Host selection by the fir engraver Scolytus ventralis (Coleoptera: Scolytidae)—preliminary field studies.* The Can. Entomol. 103:1717-1725, illus.
Rates of insect visitations on lower poles of white firs were 10 times higher than on Jeffrey pines with two to three times as many beetles trapped near girdled or severed white firs than on uninjured firs.

1173. Ferrell, George T.
1973. *Stand and tree characteristics influencing density of fir engraver beetle attack scars in white fir.* USDA Forest Serv. Res. Paper PSW-97, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The highest scar densities were found in intermediate and suppressed fir recently killed by the fir engraver in a heavily cutover stand growing on the lowest quality site studied.

1174. Ferrell, George T.
1973. *Weather, logging, and tree growth associated with fir engraver attack scars in white fir.* USDA Forest Serv. Res. Paper PSW-92, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Concludes that it is feasible to develop models for predicting the amount of fir damage by the fir engraver, given current and previous levels of logging, precipitation, and tree growth.

1175. Ferrell, George T.
1974. *Moisture stress and fir engraver (Coleoptera: Scolytidae) attack in white fir infected by true mistletoe.* Can. Entomol. 106:315-318.
Moisture stress in the upper crowns of most of the infected fir exceeded that in uninfected trees; no defferences in moisture stress between infected and uninfected trees were found at the lower, and mid-crown levels.

1176. Ferrell, George T., and Ralph C. Hall.
1975. *Weather and tree growth associated with white fir mortality caused by fir engraver and roundheaded fir borer.* USDA Forest Serv. Res. Paper PSW-109, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Concludes that increased fir mortality caused by subcortical insects occurs during periods of drought and reduced fir growth, probably in response to decreased resistance of fir to the beetles.

1177. Fowells, Harry A.
1940. *Cutworm damage to seedlings in California pine stands.* J. For. 38(7):590-591.

Presents a table indicating the extent of damage for a five-year period in five artificially seeded study areas of white fir types.

1178. Hall, Ralph C.
1955. *Insect damage to the 1954 crop of Douglas-fir and sugar pine cones and seeds in northern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 18, 4 p. Berkeley, Calif.

Revealed an average loss by seed and cone insects of 82.2 percent of Douglas-fir and 75.1 percent of sugar pine seed.

1179. Hall, Ralph C.
1957. *Pine reproduction weevil.* U.S. Dep. Agric. Forest Pest Leafl. 15, 4 p., illus.

Reports on life history and habits, and includes recommendations for control.

1180. Hall, Ralph C.
1958. *Environmental factors associated with outbreaks of the western pine beetle and the California five-spined engraver in California.* Tenth Int. Congr. Entomol. Proc. 4:341-347.

Environmental studies indicate that beetle-caused mortality of ponderosa pine is associated with deficiencies in precipitation and soil moisture, and high temperatures during the growing season.

1181. Hall, Ralph C.
1958. *Sanitation-salvage controls bark beetles in southern California recreation area.* J. For. 56(1):9-11, illus.

Cutting high-risk trees in the Barton Flats Recreational Area resulted in a reduction in bark beetle-caused losses at a savings to the government.

1182. Hall, Ralph C., and Charles B. Eaton.
1969. *Cooperative forest insect detection reports for California, for the calendar year 1959.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 170, 8 p., illus. Berkeley, Calif.

Reports are tabulated according to the insect involved, the species of plant attacked, and the source of the report, and are compared to reports of the previous year.

1183. Hall, Ralph C.
1965. *Sagebrush defoliator outbreak in northern California.* U.S. Forest Serv. Res. Note PSW-75, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Reports observations on the biology and habits of the pest, and extent of damage which includes varying degrees of defoliation and mortality in California, Oregon, and Nevada in 1963 and 1964.

1184. Heller, Robert C.
1974. *Remote sensing as an inventory tool for forest insect surveys.* In *Proceedings, Monitoring Forest Environment Through Successive Sampling.* p. 321-343. [Syracuse, N.Y., June 24-26, 1974.]

Visual surveys are useful and less costly than photographic surveys, which are more accurate; resolution of ERTS data is too coarse for this purpose.

1185. Hill, C. L.
1926. *Fight on marine borers in S. F. harbor.* Calif. Eng. 4(6):172-173.

Describes the extensive damage inflicted on waterfront structures and states that the most effective protection scheme is pressure treatment with creosote oil.

1186. Hill, C. L., and C. A. Kofoid.
1927. *Marine borers and their relation to marine construction on the Pacific coast.* 357 p. Final report of the San Francisco Bay Marine Piling Committee prepared under the direction of the San Francisco Bay Marine Piling Committee cooperating with the National Research Council and the American Wood-Preservers' Association.

A comprehensive book with extensive historical, hydrographic, engineering, chemical, and biological material.

1187. Keen, F. P.
1955. *The western pine beetle.* U.S. Dep. Agric. Forest Pest Leafl. 1, 4 p., illus.

Means of recognizing the insect and its damage, its habits, and natural and direct control measures are given.

1188. Keen, F. P.
1958. *Cone and seed insects of western forest trees.* U.S. Dep. Agric. Tech. Bull. 1169, 168 p., illus.

Covers research between 1912 and 1917 and includes information on insects reared from major and minor

conifers with notes on the insects' biologies, hosts, parasites and predators, and gives references through the year 1956.

1189. Koerber, Thomas W.
1960. *Insects destructive to the Douglas-fir seed crop in California . . . a problem analysis.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 45, 36 p., illus. Berkeley, Calif.
Reviews the available information on these insects and outlines a research program aimed at the development of methods for controlling them.

1190. Koerber, Thomas W.
1963. *Leptoglossus occidental is (Hemiptera: Coreidae). A newly discovered pest of coniferous seed.* Entomol. Soc. Am. Ann. 56(2):229-234, illus.
This large coreid bug, which feeds on the cones and staminate strobili of Douglas-fir and several species of pine, is responsible for seeds with shrunken, spongy endosperm.

1191. Koerber, Thomas W.
1967. *Introduction to protection problems in young-growth stands—insects.* Conf. on Young-growth Forest Manage. Proc. 1967:120-123.
Insects damage young-growth stands by reducing growth rates and deforming or killing trees.

1192. Koerber, Thomas W., and Boyd E. Wickman.
1970. *Use of tree ring measurements to evaluate impact of insect defoliation.* Proc. Conf. on Tree Ring Anal., Univ. B.C., Vancouver, 1970:101-106, illus.
Measurements may be used to estimate the loss caused by insects, to date older insect epidemics, and to predict the outcome of outbreaks by defoliators.

1193. Koerber, Thomas W., and George R. Struble.
1971. *Lodgepole needle miner.* USDA Forest Pest Leafl. 22 (rev.), 8 p., illus.
This revision updates an earlier Forest Pest Leaflet on this pest of lodgepole pine forests in the west.

1194. Koerber, Thomas W.
1972. *The forest pest situation in California.* In *Permanent Association Committees Proceedings.* p. 53-54. West. For. and Conserv. Assoc., Portland, Oreg.
Traditional insect problems are at a low ebb, but a new problem—an eastern tip moth—has developed in southern California.

1195. Koerber, Thomas W.
1973. *Return of the lodgepole needle miner.* Yosemite 43(2):3-4, illus.
The lodgepole needle miner may seem to have returned to Yosemite National Park, but actually has never been away, and is now low in numbers.

1196. Krugman, Stanley L., and Thomas W. Koerber.
1969. *Effect of cone feeding by Leptoglossus occidentalis on ponderosa pine seed development.* Forest Sci. 15(1):104-111, illus.
The type of damage varies with the stage of development of the seed.

1197. Lyon, Robert L.
1955. *A secondary sex character on the male of the California five-spined engraver, Ips confusus (Lec.).* Can. Entomol. 87:482-483, illus.
Describes a tiny embossment on the face of the male which is 99 percent reliable in separating the males from the females for entomological studies.

1198. Lyon, Robert L.
1958. *California flatheaded borer.* U.S. Dep. Agric. Forest Pest Leafl. 24, 7 p., illus.
Gives an account of the distribution, hosts, life stages, habits, evidence of attack, and methods of control.

1199. Lyon, Robert L.
1958. *A useful secondary sex character in Dendroctonus bark beetles.* Can. Entomol. 90(10):582-584, illus.
Sexing adults by examining the seventh abdominal tergite under 10X-15X magnification is shown to be both a rapid and accurate method for the entire genus.

1200. Lyon, Robert L., and Harold W. Flake, Jr.
1966. *Rearing Douglas-fir tussock moth larvae on synthetic media.* J. Econ. Entomol. 59(3):696-698, illus.
A procedure used to rear this insect from egg stage to fourth through seventh instar can be used on large numbers of larvae.

1201. Lyon, Robert L.
1970. *California flatheaded borer.* Forest Pest Leafl. 24, 8 p., illus.
This pest primarily attacks ponderosa and Jeffrey pine, but also attacks other pine species.

1202. Lyon, Robert L., C. E. Richmond, J. L. Robertson, and B. A. Lucas.
1972. *Rearing diapause and diapause-free western spruce budworm (Choristoneura occidentalis) (Lepidoptera: Toricidae) on an artificial diet.* Can. Entomol. 104:417-426, illus.
By eliminating diapause it was possible to rear about 7½ generations each year instead of about 2¼ under normal diapause conditions.

1203. Miller, J. M., and F. P. Keen.
1960. *Biology and control of the western pine beetle.* U.S. Dep. Agric. Misc. Publ. 800, 381 p., illus.
Reviews the results of 50 years of research involving every phase of the bark beetle problem.

1204. Moore, Arthur D.
1955. *Ips confusus (Lec.) adults infected with nematodes.* J. Econ. Entomol. 48(4):478.
Two species of nematodes infect this insect, but there was no correlation between mortality among the beetles and the presence of these parasites.

1205. Nelson, Robert E., and Clifton J. Davis.
1972. *Black twig borer . . . a tree killer in Hawaii.* USDA Forest Serv. Res. Note PSW-274, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The beetle and its associated microorganisms have been associated with the death of five tree species in planted forests on Oahu.

1206. Oliver, William W.
1968. *Sapsucker damage to ponderosa pine.* J. For. 66(11):842-844, illus.
Observations in a stand of pole-sized pine in northeastern California suggest that sapsuckers feed repeatedly on favorite trees and that old wounds act as an attractant.

1207. Oliver, William W.
1970. *The feeding pattern of sapsuckers on ponderosa pine in northeastern California.* The Condor 72(2):241.
Observations suggest that sapsuckers feed repeatedly on favorite trees, often singling them out because of old pole wounds.

1208. Person, Hubert L.
1930. *A forest insect epidemic.* Calif. Countryman 16(7):11, 31.
Tells how a destructive outbreak of *Dendroctonus brevicomis* and the ensuing salvage logging and control measures stimulated the industrial growth of Modoc County.

1209. Person, Hubert L.
1931. *Theory in explanation of the selection of certain trees by the western pine beetle.* J. For. 29(5):696-699.
Volatile oils in subnormal trees attract beetles from the immediate vicinity, these introduce a yeast into the inner bark producing a fermentation strong enough to attract other beetles from a wider radius.

1210. Person, Hubert L.
1932. *Defoliating insect active in California brush fields.* Forest Worker 8(6):14.
Reports on a renewed outbreak of *Aglais californica* and the defoliation of large areas of *Ceanothus thyrsiflorus.*

1211. Person, Hubert L.
1933. *Redwood has few insect enemies.* Forest Worker 9(3):15-16.
Briefly discusses the few insects which have been known to attack redwood.

1212. Powers, Robert F., and William E. Sundahl.
1973. *Sequoia pitch moth, a new problem in fuel-break construction.* J. For. 71(6):338-339, illus.
Resin may accumulate at tree bases in large amounts after repeated attacks and could be a problem if light ground fires are planned.

1213. Reece, C. A., J. O. Rodin, R. G. Brownlee, W. G. Duncan, and R. M. Silverstein.
1968. *Synthesis of the principal components of the sex attractant from male Ips confusus frass: 2-methyl-6-methylene-7-octen-4-ol, 2-methyl-6-methylene-2, 7-octadien-40-ol, and (+)-cis-verbenol.* Tetrahedron 24:4249-4256.
Reports the synthesis of three terpene alcohols.

1214. Richmond, Charles E.
1972. *Juvenile hormone analogues tested on larvae of western spruce budworm.* J. Econ. Entomol. 65(4):950-953, illus.
At low dosages, the effects were decreased egg production and hatch whereas the higher dosages resulted in increasing morphogenetic juvenilization.

1215. Shifrine, Moshe, and H. J. Phaff.
1956. *The association of yeasts with certain bark beetles.* Mycologia 48(1):41-55.
Describes 169 isolations of yeast found in several western species of bark beetles and discusses certain typical physiological properties of these yeast isolates.

1216. Silverstein, R. M., J. Otto Rodin, and David L. Wood.
1966. *Sex attractants in frass produced by male Ips confusus in ponderosa.* Science 154(3748):509-510.
The attractant response by *Ips confusus* to frass produced by male beetles can be reproduced in a laboratory bioassay.

1217. Smith, Richard H.
1956. *The rearing of Lyctus planicollis and the preparation of wood for control tests.* J. Econ. Entomol. 49(1):127-129.
Oak and hickory limbwood, cut during the dormant

season of growth and seasoned rapidly, was found best for rearing the beetle in large numbers.

1218. Smith, Richard H.
1956. *A technique for studying the oviposition habits of the southern lyctus beetle and its egg and early larval stages.* J. Econ. Entomol. 49(2):263-264, illus.
Discusses the technique of exposing several springwood vessels along the tangential surface of hickory, and then tightly covering them with glass to provide observation "windows".

1219. Smith, Richard H., and R. E. Lee.
1957. *Black turpentine beetle.* U.S. Dep. Agric. Forest Pest Leafl. 12, 7 p., illus.
Describes life history and habits, and includes control recommendations.

1220. Smith, Richard H.
1957. *Death of a pine.* Forest Farmer. 15(12):7, illus.
Describes the progressive deterioration of slash pine killed by the black turpentine beetle.

1221. Smith, Richard H.
1957. *Habits of attack by the black turpentine beetle on slash and longleaf pines in north Florida.* J. Econ. Entomol. 50(3):241-244, illus.
An analysis of life history and habits with particular emphasis on time and location of attacks.

1222. Smith, Richard H.
1958. *Additional host records for two bostrichid powder-post beetles.* J. Econ. Entomol. 51(4):556.
Reports of the indigenous species, *Scobicia declivis* (Lec.), found attacking imported logs of Philippine mahogany, are contrasted with an earlier record cited of a non-indigenous species, *Heterobostrychus aequalis* (Waterh.) found in hickory returned to this country from the Philippines.

1223. Smith, Richard H.
1960. *Resistance of pines to the pine reproduction weevil, Cylindrocopturus eatoni.* J. Econ. Entomol. 53(6):1044-1048, illus.
A review of the early work is presented along with the results of experiments on the resistance of interspecific and intraspecific pine hybrids to attack of this insect.

1224. Smith, Richard H.
1961. *The fumigant toxicity of three pine resins to Dendroctonus brevicomis and D. jeffreyi.* J. Econ. Entomol. 54(2):365-369, illus.
The hypothesis that bark beetles can tolerate the resin vapor of their hosts but cannot tolerate that of a non-host is presented and supported with data from experiments.

1225. Smith, Richard H.
1961. *Red turpentine beetle.* U.S. Dep. Agric. Forest Pest Leafl. 55, 8 p., illus.
Reviews distribution, life stages, life history, symptoms and habits of attack, and control of the beetle.

1226. Smith, Richard H.
1961. *Techniques for determining the toxicity of pine resin vapors to Dendroctonus brevicomis and D. jeffreyi.* J. Econ. Entomol. 54(2):359-365, illus.
Fumigation chambers, methods of resin collection, and methods of obtaining vapor dosage are described, and results given.

1227. Smith, Richard H.
1963. *Preferential attack by Dendroctonus terebrans on Pinus elliottii.* J. Econ. Entomol. 56(6):817-819.
This beetle is highly attracted by other attacks and exhibits the 'mass attack' habit noted for other scolytids.

1228. Smith, Richard H., and Charles B. Eaton.
1963. *Studies on resistance of pines to insects.* 6 p. Food and Agric. Organ., U.N., Rome, Italy.
Considerable success has been achieved in empirically identifying species resistant to the weevil, and some progress has been made toward determining the casual mechanism for this resistance.

1229. Smith, Richard H.
1963. *Toxicity of pine resin vapors to three species of Dendroctonus bark beetles.* J. Econ. Entomol. 56(6):827-831, illus.
The hypothesis that these beetles can tolerate a saturated atmosphere of resin vapors from host pines but not those from nonhost pines was tested with the result that qualitative differences in resins seem to affect the resistance of pines to bark beetles.

1230. Smith, Richard H.
1965. *Effect of monoterpene vapors on the western pine beetle.* J. Econ. Entomol. 58(3):509-510, illus.
There was significantly different mortality by the vapors of different monoterpenes of its primary host, *Pinus ponderosa.*

1231. Smith, Richard H.
1965. *A physiological difference among beetles of Dendroctonus ponderosae (= D. monticolae) and D. ponderosae (= D. jeffreyi).* Ann. Entomol. Soc. Am. 58(4):440-442, illus.
Reports a distinct difference was found between the beetles in their reaction to pine resin vapors and their individual components.

1232. Smith, Richard H.
1966. *Forcing attacks of western pine beetles to test*

resistance of pines. U.S. Forest Serv. Res. Note PSW-119, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Tree-killing attacks were obtained by attracting beetles to groups of pines, with freshly infested bolts as the attractant, and by en masse forced attack on trees subjected to mechanical and biological stress.

1233. Smith, Richard H.
1966. *Research and development of pines resistant to the pine reproduction weevil, Cylindrocopturus eatoni Buch.* Proc. N.A.T.O. and N. S. F. Symp., Penn. State Univ., 1964:363-365.
Recent studies strengthen earlier conclusions that ponderosa and Jeffrey pine are quite susceptible, that progeny of Apache, Montezuma, and Arizona pine are extremely susceptible, and that there is considerable intraspecific variation in resistance of Jeffrey and ponderosa pine.

1234. Smith, Richard H.
1966. *Resin quality as a factor in the resistance of pines to bark beetles.* Proc. N.A.T.O. and N.S.F. Symp., Penn. State Univ., 1964:189-196.
Reviews previous work on risk rating, oleoresin pressure, and resin toxicity and discusses three recent studies which suggest that intraspecific variation in monoterpene composition might be a factor in resistance.

1235. Smith, Richard H., and R. J. Kowal.
1968. *Attack of the black turpentine beetle on roots of slash pine.* J. Econ. Entomol. 61(5):1430-1432, illus.
Root damage by this insect may actually be responsible for the death of those trees that apparently die from a relatively small amount of trunk attack.

1236. Smith, Richard H.
1969. *Xylem resin as a factor in the resistance of pines to forced attacks by bark beetles.* Proc. Second World Consult. on Forest Tree Breeding (FAO) FO-FTB-69-5/6, 13 p., illus.
Both the amount and the terpene composition of xylem resin have a marked effect on the success of forced attacks.

1237. Smith, Richard H.
1971. *Red turpentine beetle.* Forest Pest Leafl. 55, 8 p., illus.
Summarizes information on this most widely distributed bark beetle in North America.

1238. Smith, Richard H., and R. E. Lee III.
1972. *Black turpentine beetle.* Forest Pest Leafl. 12 (rev.), 8 p., illus.
Summarizes information on the life history, habits, and natural control of a pest existing throughout the pine belt of the Southern United States.

1239. Smith, Richard H.
1972. *Xylem resin in the resistance of the Pinaceae to bark beetles.* USDA Forest Serv. Gen. Tech. Rep. PSW-1, 7 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reviews evidence supporting the hypothesis that xylem resin plays a major role both in resistance and in susceptibility of *Pinaceae.*

1240. Smith, Richard H.
1975. *Formula for describing effect of insect and host tree factors on resistance to western pine beetle attack.* J. Econ. Entomol. 68(6):841-844.
Proposes a formula in which resistance = [(resin quantity, resin quality)÷(beetle attack density, beetle quality)], and resin quality is measured by xylem monoterpene composition.

1241. Stevens, Robert E.
1957. *Fir engraver beetle.* U.S. Dep. Agric. Forest Pest Leafl. 13, 7 p., illus.
A summary of the available information on the life history, habits, and control of the fir engraver.

1242. Stevens, Robert E.
1957. *Insect-caused damage to the 1956 Douglas-fir cone crop in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 120, 2 p. Berkeley, Calif.
Examination of samples of Douglas-fir cones revealed that insects caused very little damage.

1243. Stevens, Robert E.
1959. *Biology and control of the pine needle-sheath miner, Zelleria Haimbachi Busck. (Lepidoptera: Hyponomeutidae).* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper PSW-30, 20 p., illus. Berkeley, Calif.
A report on distribution, life history, habits, and control methods.

1244. Stevens, Robert E.
1959. *Surveys of Douglas-fir cone and seed insect damage in northeastern California, 1954-1958.* J. For. 57(12):897-899, illus.
Describes the important insects and the survey conducted in which some relatively insect-free areas were found.

1245. Stevens, Robert E.
1959. *What's wrong with my trees?—Douglas-fir*

damaged by engraver beetles. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 30, 2 p., illus. Berkeley, Calif.
Describes damage caused by the Douglas-fir engraver, habits of the insect, and causes of the outbreak.

1246. Stevens, Robert E., and Ralph C. Hall.
1960. *Beetles and burned timber.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 49, 2 p., illus. Berkeley, Calif.
Reports danger of severe damage from bark beetles and wood borers around the sites of 1959 timber fires and suggests steps to minimize losses.

1247. Stevens, Robert E.
1961. *Pine needle-sheath miner.* U.S. Dep. Agric. Forest Pest Leafl. 65, 4 p., illus.
Illustrates life history, life stages, evidence of infestation, and habits, and presents historical, distributional, host-range, and control information.

1248. Stevens, Robert E., and Ronald W. Stark.
1962. *Sequential sampling for the lodgepole needle miner, Evagora milleri.* J. Econ. Entomol. 55(4):491-494, illus.
Presents a system, designed primarily for use in extensive surveys and control operations, which provides for population estimates in four infestation categories.

1249. Stevens, Robert E.
1965. *Observations on the Yosemite bark weevil in California.* Pan-Pacific Entomol. 42(3):184-189, illus.
The weevil, widely distributed in Pacific Coast pine forests, infests seedlings and saplings growing under adverse conditions and sometimes larger trees, which are dying.

1250. Stevens, Robert E.
1965. *Pine reproduction weevil.* U.S. Forest Pest Leafl. 15 (rev.), 6 p., illus.
Describes the biology of a serious pest in California, which makes ponderosa pine its primary host.

1251. Stevens, Robert E.
1966. *Ponderosa pine tip moth.* U.S. Forest Serv. Forest Pest Leafl. 103, 5 p., illus.
The larvae, found in young trees in the pine forests of the Sierra Nevada and Cascade Ranges, feed in the new shoots, causing varying amounts of tree deformation.

1252. Stevens, Robert E.
1966. *The ponderosa pine tip moth, Rhyacionia zozana, in California (Lepidoptera: Olethreutidae).* Ann. Entomol. Soc. Am. 59(1):186-192, illus.
Reports life history and habits, associated insects, and insect-tree relationships.

1253. Stevens, Robert E.
1971. *Pine needle sheath miner.* Forest Pest Leafl. 65 (rev.), 5 p., illus.
Summarizes information on the pine needle-sheath miner and its distribution and infestations.

1254. Stevens, Robert E.
1971. *Ponderosa pine tip moth.* Forest Pest Leafl. 103 (rev.), 5 p., illus.
Summarizes information on this pest of foothill pine forests of the Sierra Nevada and Cascade Ranges in California, Oregon, and Washington.

1255. Struble, George R., and Ralph C. Hall.
1954. *Telephone cables invaded by shrub bark beetle in Pacific coastal region.* J. Econ. Entomol. 47(5):933-934.
Describes an unusual type of damage to polyethylene cable by an insect that normally breeds in cascara.

1256. Struble, George R.
1955. *The California five-spined engraver beetle.* U.S. Dep. Agric. Forest Pest Leafl. 4, 4 p.
Discusses insect damage, life history, habits, and preventive control through proper treatment of slash.

1257. Struble, George R., and Ralph C. Hall.
1955. *The California five-spined engraver, its biology and control.* U.S. Dep. Agric. Circ. 964, 21 p., illus.
Discusses the character of outbreaks, seasonal history and habits, conditions favoring optimum brood development and outbreaks, and biological and applied control.

1258. Struble, George R., and Philip C. Johnson.
1955. *The mountain pine beetle.* U.S. Dep. Agric. Forest Pest Leafl. 2, 4 p., illus.
Discusses recognition, behavior from egg to adult, natural control by parasites, predators, and low temperature, and applied control by such means as salvage logging, chemical sprays, and solar heat.

1259. Struble, George R.
1957. *Biology and control of the white-fir sawfly.* Forest Sci. 3(4):306-313.
A report on the life history and habits with an appraisal of the damage caused, observations on natural control, and recommendations for chemical control.

1260. Struble, George R.
1957. *The fir engraver, a serious enemy of western true firs.* U.S. Dep. Agric. Prod. Res. Rep. 11, 18 p., illus.

A report on the life history and habits of the fir engraver beetle, with additional notes on the character of damage, associated insects, and control measures.

1261. Struble, George R., and William D. Bedard.
1958. *Arthropod enemies of the lodgepole needle miner, Recurvaria milleri Busck (Lepidoptera: Gelechiidae).* Pan-Pacific Entomol. 34(4):181-186.
Contains an annotated list of parasitic and predaceous arthropod enemies and includes a short resume of what is known about the value of several species as control agents.

1262. Struble, George R.
1958. *Lodgepole needle miner.* U.S. Dep. Agric. Forest Pest Leafl. 22, 7 p., illus.
Contains information on the range, hosts, life stages, and habits, and discusses evidence of infestation and biological and chemical control measures.

1263. Struble, George R.
1959. *Egg sampling reveals trend in white-fir sawfly abundance.* J. For. 57(7):510-511, illus.
Two widely separated infested areas were sampled annually from 1953 through 1959 using a sampling technique for the egg stage which provided a good method of estimating the potential damage by larvae.

1264. Struble, George R., and Mauro E. Martignoni.
1959. *Role of parasites and disease in controlling the lodgepole needle miner, Recurvaria milleri Busck (Lepidoptera: Gelechiidae).* J. Econ. Entomol. 52(3):531-532.
At present, parasites are the most important natural enemies of the lodgepole needle miner in the outbreak at Yosemite National Park.

1265. Struble, George R.
1961. *Monterey pine ips.* U.S. Dep. Agric. Forest Pest Leafl. 56, 7 p., illus.
Describes and illustrates evidence of infestation, life stages, life history, and habits, and includes distributional data and a discussion of natural and applied control.

1266. Struble, George R., and Philip C. Johnson.
1964. *Black pine-leaf scale.* U.S. Dep. Agric. Forest Pest Leafl. 91, 6 p., illus.
Describes life stages, habits and evidence of infestation, and includes information on natural and chemical control.

1267. Struble, George R.
1965. *Attack pattern of mountain pine beetle in sugar pine stands.* U.S. Forest Serv. Res. Note PSW-60, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Data accumulated in old-growth stands revealed preferences by the mountain pine beetle for mature and overmature trees with the most decadent crowns, whereas in second-growth stands, beetle outbreaks were non-discriminating between trees.

1268. Struble, George R.
1965. *Field test of Bacillus thuringiensis (Berliner) to control the lodgepole needle miner.* J. Econ. Entomol., 58(5):1005-1006.
Summarizes results of a field test conducted in 1963 on the pathogenic capabilities of Thuricide 90-T against first instar larvae in Yosemite National Park.

1269. Struble, George R.
1966. *California five-spined ips.* U.S. Forest Serv. Forest Pest Leafl. 102, 4 p., illus.
Describes the economic importance, host material, life history, and habits of this insect and suggests means of natural, preventive, and applied control.

1270. Struble, George R.
1967. *Insect enemies in the natural control of the lodgepole needle miner.* J. Econ. Entomol. 60(1):225-228.
Study of insect enemies in more than five host generations show that they have low potential for control.

1271. Struble, George R.
1967. *Lodgepole needle miner, Coleotechnites (Recurvaria) milleri (Busck).* In *Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico.* A. G. Davidson and R. M. Prentice, eds., Can. Dep. For. and Rural Dev. Publ. 1180, p. 99-102.
Summarizes information on the distribution, hosts, and life history of this insect and outlines suggested control measures.

1272. Struble, George R.
1968. *Infestations and biology of the white-fir needle miner in California red fir.* J. Econ. Entomol. 61(4):1093-1097, illus.
Reports infestation in red and white fir in 1965 and shows from subsequent studies that the insect has overlapping generations, each requiring two years.

1273. Struble, George R.
1968. *Needle miner infestation . . . in lodgepole pine east of the Sierra Crest.* USDA Forest Serv. Res. Note PSW-177, 2 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The lodgepole needle miner in the Inyo National

Forest begins its 2-year cycle in even-numbered years whereas *Coleotechnites milleri* (Busck) in Yosemite National Park begins its in the odd-numbered years.

1274. Struble, George R.
1969. *Gall wasp infestations in forest trees, chiefly pines, of California (Hymenoptera: Eurytomidae).* Pan-Pacific Entomol. 45(2):112-115, illus.
Distribution extends from San Diego to Shasta County, and coastal and interior mountains.

1275. Struble, George R.
1973. *Biology, ecology, and control of the lodgepole needle miner.* U.S. Dep. Agric. Tech. Bull. 1458, 38 p., illus.
Long-lasting infestations cause serious damage in high-elevation lodgepole pine forests of the Western United States and Canada.

1276. Tate, Nancy L., and William D. Bedard.
1967. *Methods of sexing live adult western pine beetles, Dendroctonus brevicomis (Coleoptera: Scylotidae).* J. Econ. Entomol. 60(6):1688-1690, illus.
The accuracy of five different methods of sexing is given, along with descriptions and illustrations of the secondary sex characteristics used in each method, and the usefulness of each method is discussed.

1277. U.S. Forest Serv., Pacific Southwest Forest and Range Experiment Station.
1961. *Forest insect conditions in the United States in 1960. California.* Forest Serv. U.S. Dep. Agric., p. 8-11, illus.
Summarizes the status of infestations of the more important California forest insects by species.

1278. U.S. Forest Serv., Pacific Southwest Forest and Range Experiment Station.
1958. *Tioga's Ghosts.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 28, 4 p. Berkeley, Calif.
Gives a popularized account of the lodgepole needle miner in Yosemite National Park and studies in progress to control it.

1279. U.S. Forest Serv., Pacific Southwest Forest and Range Experiment Station.
1959. *Bark beetle threatens California pines.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 41, 2 p., illus. Berkeley, Calif.
Increased bark beetle populations have resulted from drought, numerous lightning-struck trees, and snow breakage.

1280. U.S. Forest Serv., Pacific Southwest Forest and Range Experiment Station.
1959. *Timber or snags in 1959?* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 34, 4 p., illus. Berkeley, Calif.
Predicts a bumper crop of bark beetles for California's pine forests and suggests preventive control measures to help hold the bark beetles in check.

1281. Waters, William E.
1974. *Sequential sampling applied to forest insect surveys.* In *Proceedings, Monitoring Forest Environment Through Successive Sampling.* p. 290-311. [Syracuse, N.Y., June 24-26, 1974.]
The practical logic of the sequential approach and its ease of application make it ideally suited for most forest insect survey purposes.

1282. Weidman, R. H., and G. T. Robbins.
1947. *Attacks of pitchmoth and turpentine beetle on pines in the Eddy Arboretum.* J. For. 45(6):428-433.
Describes attacks on native and introduced pines providing an unusual opportunity to observe relative susceptibility, parts of the tree attacked, and influence of pruning scars.

1283. Wickman, Boyd E.
1958. *Mortality of white fir following defoliation by the Douglas-fir tussock moth in California, 1957.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 137, 4 p., illus. Berkeley, Calif.
Defoliation between 1954 and 1956 resulted in considerable tree mortality.

1284. Wickman, Boyd E.
1962. *California oakworm.* U.S. Dep. Agric. Forest Pest Leafl. 72, 4 p., illus.
Describes and illustrates life history, habits, and damage and discusses control and distribution.

1285. Wickman, Boyd E.
1962. *Effects of defoliation by the Great Basin tent caterpillar on greenleaf manzanita and mountain whitethorn ceanothus.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 204, 3 p., illus. Berkeley, Calif.
No appreciable brush mortality resulted from an insect outbreak of three years' duration which severely defoliated the species studied.

1286. Wickman, Boyd E., and Charles B. Eaton.
1962. *The effects of sanitation-salvage cutting on insect-caused pine mortality at Blacks Mountain Experimental Forest 1938-1959.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 66, 39 p., illus. Berkeley, Calif.

Bark beetle-caused losses in old-growth pine are summarized and compared on uncut and sanitation-salvage-cut compartments.

1287. Wickman, Boyd E.
1963. *The large aspen tortrix, Choristoneura conflictana in California (Lepidoptera: Tortricidae).* J. Econ. Entomol. 56(5):593-596, illus.
Reports the first outbreak, in 1960, of a defoliator rarely collected in California since its discovery in 1922.

1288. Wickman, Boyd E.
1963. *Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth.* U.S. Forest Serv. Res. Paper PSW-7, 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
In 5 years after a 1954-56 outbreak in Calaveras and Tuolumne Counties, 20 percent of the merchantable white fir was lost owing to radial growth reductions in partly defoliated trees, and 12 percent of these trees were top-killed.

1289. Wickman, Boyd E.
1964. *Attack habits of Melanophila consputa Lec. (Coleoptera: Buprestidae) on fire-killed pines.* Pan-Pacific Entomol. 40(3):183-186, illus.
Large numbers of adults mating and ovipositioning on scorched pines during a fire resulted in subsequent larvae monopolizing available space under the bark of attacked trees, and excluding other wood borers and bark beetles.

1290. Wickman, Boyd E.
1964. *A comparison of radiographic and dissection methods for measuring siricid populations in wood.* Can. Entomol. 96(3):508-510.
Estimates of numbers of siricids in white fir obtained by the two methods were very closely correlated, with the radiographic methods being more accurate than dissection alone.

1291. Wickman, Boyd E.
1964. *Freshly scorched pines attract large numbers of Arhopalus asperatus adults (Coleoptera: Cerambycidae).* Pan-Pacific Entomol. 40(1):59-60.
Records a hitherto unreported response of the insect species to fire-injured trees.

1292. Wickman, Boyd E.
1964. *Observations on oviposition habits of Sirex longicauda Middlk. and Urocerus californicus (Hymenoptera: Siricidae).* Pan-Pacific Entomol. 40(4):259-261.
Reports oviposition habits of two North American siricids which are similar to those reported for European species except for temperature relationships.

1293. Wickman, Boyd E.
1964. *Observations on the siricid parasite Ibalia ensiger (Hymenoptera: Ibalidae).* Pan-Pacific Entomol. 40(1):19-20.
Notes the importance of this insect and tells of a large flight of adults seen near siricid-infested lumber.

1294. Wickman, Boyd E.
1965. *Black-backed three-toed woodpecker, Picoides arcticus, predation on Monochamus oregonensis (Coleoptera: Cerambycidae).* Pan-Pacific Entomol. 41(3):162-164.
Field observations and a stomach analysis made in 1964 indicate that this woodpecker can be an important predator of wood borers.

1295. Wickman, Boyd E.
1965. *Insect-caused deterioration of windthrown timber in northern California 1963 and 1964.* U.S. Forest Serv. Res. Paper PSW-20, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Finds that the principal tree degrade was caused by blue stain fungi introduced by bark beetles and flatheaded borers, and that roundheaded borers caused the most serious wood boring.

1296. Wickman, Boyd E.
1965. *Use of radiography to detect mortality of California flatheaded borers in pine bark.* J. Econ. Entomol. 59(4):1028-1030, illus.
Reports that dead, late-instar larvae were easily found by using radiography.

1297. Wickman, Boyd E.
1967. *Evaluating the impact of insects in young-growth stands.* Conf. on Young-growth Forest Manage. Proc. 1967:127-130.
Reports information on bark beetles and defoliators, on the kind of damage they can do, and suggests how damage can be measured.

1298. Wickman, Boyd E.
1967. *Life history of the incense-cedar wood wasp, Syntexis libocedrii Rohwer (Hymenoptera: Syntexidae).* Ann. Entomol. Soc. Am. 60(6):1291-1295, illus.
Describes this heretofore rare wood borer that heavily infested sapling-sized incense-cedar on a forest burn near Viola, California in 1963.

1299. Wickman, Boyd E.
1968. *The biology of the fir tree borer, Semanotus*

litigiosus (Casey) (Coleoptera: Cerambycidae), in California. Can. Entomol. 100(2):208-220, illus.
Adults attack in early spring, laying eggs in bark crevices, then damage is caused by the larvae boring up to 3 inches into wood to build pupal chambers.

1300. Wickman, Boyd E.
1968. *Fir tree borer.* Forest Pest Leafl. 115, 6 p., illus.
The borer can be an economic pest by causing lumber degrade and sometimes legal problems for lumber manufacturers.

1301. Wickman, Boyd E., and Serje G. Seminoff.
1968. *Notes on the biology of Eucrossus villicornis LeConte (Coleoptera: Cerambycidae).* Pan-Pacific Entomol. 44(4):321-324, illus.
The species found in the Western United States and in Northern Mexico appears to have a 1-year life cycle in its normal range, but may have either a 1-year or 2-year cycle in cooler climates further north.

1302. Wickman, Boyd E., and Richard H. Hunt.
1969. *Biology of the phantom hemlock looper on Douglas-fir in California.* J. Econ. Entomol. 62(5):1046-1050, illus.
Reports the location and extent of the first known California outbreak of this species.

1303. Wickman, Boyd E.
1969. *Wood borers attracted to turpentine in windthrown timber in northern California.* USDA Forest Serv. Res. Note PSW-195, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Several species and their predators were caught most consistently on downwind versus upwind traps, indicating an attraction for turpentine.

1304. Williams, Carroll B., Jr.
1967. *Spruce budworm damage symptoms related to radial growth of grand fir, Douglas-fir, and Englemann spruce.* Forest Sci. 13(3):274-285, illus.
Reduction in radial increment generally differed significantly between four damage classes used in the study.

1305. Williams. Carroll B., Jr., Patrick J. Shea, and Gerald S. Walton.
1971. *Population density of western spruce budworm as related to stand characteristics on the Bitterroot National Forest.* USDA Forest Serv. Res. Paper PSW-72, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Densities of spruce budworm populations were strongly related to plot basal area, tree species, tree crown level, and current and past levels of tree defoliation.

1306. Wood, David L., Lloyd E. Browne, William D. Bedard, and P. E. Tilden.
1968. *Response of Ips confusus to synthetic sex pheromones in nature.* Science 159:1373-1374.
Synthetic sex pheromones appeared to elicit the same response as natural attractants from male-infested bolts of ponderosa pine.

1307. Wyckoff, Stephen H., Carl Hartley, and Leslie W. Orr.
1947. *Protection against forest insects and diseases in the United States.* U.S. Forest Serv. Reappraisal of the forest situation. Rep. 5, 39 p.
Discusses endemic and epidemic states of insect activity, losses from insect and diseases, costs and methods of protection and offers a plan for control.

Forest Diseases

1308. Bega, Robert V.
1957. *The use of detached ribes and pine leaves in studies with Cronartium ribicola.* Phytopathology 47:9.
Reports on the technique and results of using detached ribes leaves and pine shoots in inoculation studies with the fungus causing white pine blister rust.

1309. Bega, Robert V.
1959. *The capacity and period of maximum production of sporidia in Cronartium ribicola.* Phytopathology 49(1):54-57.
Studies in a specially designed climate control chamber showed that representative peak production of sporidia began after 14 hours of 100 percent humidity and continued for another 30 hours.

1310. Bega, Robert V., and Richard S. Smith.
1960. *Diseases threaten forest nurseries.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 52, 3 p., illus. Berkeley, Calif.
Identifies the diseases isolated from seedlings collected at various nurseries, outlines possible control measures and includes a brief discussion of the impact of nursery diseases on reforestation.

1311. Bega, Robert V.
1960. *The effect of environment on germination of sporidia in Cronartium ribicola.* Phytopathology 50:61-69.

Spores of this fungus were held under controlled conditions to determine the effect on germination of light, temperature, pH, and substrate (the needles of several white pines).

1312. Bega, Robert V., and Richard S. Smith.
1960. *Thermal death range of sclerotia of Macrophomina phaseoli.* Phytopathology 50:9.
Gives results of the thermal inactivation of the fungus causing root rot in forest nurseries.

1313. Bega, Robert V., and Richard S. Smith.
1962. *Time-temperature relationships in the thermal inactivation of the sclerotia of Macrophomina phaseoli.* Phytopathology 52:632-635.
Thermal inactivation was reached at 50° C. for 2 hours, 55° C. for 8-12 minutes, and 60° C. for 30-120 seconds.

1314. Bega, Robert V.
1962. *Tree killing by Fomes annosus in a genetics arboretum.* Plant Dis. Rep. 46(2):107-110, illus.
Fomes annosus was found responsible for large-scale killing of pines, including 24 species, 3 varieties, and 1 artificial hybrid of the subgenus *Diploxylon.*

1315. Bega, Robert V., and F. F. Hendrix.
1962. *Variation of monobasidiospore isolates of Fomes annosus.* Phytopathology 52(1):3.
A genetic study demonstrated a high degree of variability in rate of growth, colony profile, and amount of asexual sporulation.

1316. Bega, Robert V.
1963. *Fomes annosus.* Phytopathology 53(10):1120-1136.
This report raises several questions on such matters as the role of basidiospores in spread of the disease, the fungus as a competiton, and the efficacy of present control methods.

1317. Bega, Robert V.
1964. *Diseases of sequoia.* In *Diseases of widely planted forest trees.* FAO/FORPEST 64, p. 131-139.
A listing and discussion of the diseases of *Sequoia sempervirens* and *S. gigantea.*

1318. Bega, Robert V., D. Dotta, D. R. Miller, and R. S. Smith, Jr.
1965. *Root disease survey at Boggs Mountain State Forest, California.* Plant Dis. Rep. 50(6):439-440, illus.
The survey found 69 infection centers, with *Fomes annosus* in 58 of the centers, *Armellaria mellea* in 7, and both pathogens in 4 centers.

1319. Bega, Robert V., and Richard S. Smith, Jr.
1966. *The distribution of Fomes annosus in natural forests of California.* Plant Dis. Rep. 50(11):32-35.
This important conifer disease is reported in all of California's National Forests and in 28 of the 58 counties.

1320. Bega, Robert V., and Howard A. Scott.
1966. *Ultrastructure of the sterigma and sporidium of Cronartium ribicola.* Can. J. Bot. 44:1726-1727.
Discusses the results of using electron micrographs of germinating teliospores to show the manner in which the sporidium is attached to the sterigma; also develops a new theory of the mechanism of sporidia discharge.

1321. Bega, Robert V.
1974. *Phytophthora cinnamomi: its distribution and possible role in ohia decline on the island of Hawaii.* Plant Dis. Rep. 58:1069-1073.
The fungus has been isolated from soil and rootlet samples throughout the "ohia decline zone."

1322. Boe, Kenneth N.
1971. *Damage to knobcone × Monterey pine hybrids and parents . . . by red band needle blight in California redwood sites.* USDA Forest Serv. Res. Note PSW-233, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Small differences in climate may be a key factor in limiting infection in hybrid plantations.

1323. Brundage, M. R.
1930. *Dipping pine to prevent stain.* Timberman 31(7):156, 158.
Describes the results of tests on a commercial scale with various chemical solutions designed to make green lumber immune to attack by blue stain fungi during the air drying process.

1324. Brundage, M. R.
1930. *Dipping treatments show substantial saving in yard stain losses.* Am. Lumberman. Whole No. 2864, p. 41.
Tests demonstrate conclusively that various chemical solutions are effective in reducing losses from yard stains in California pines.

1325. Brundage, M. R.
1930. *Dipping treatments.* West Coast Lumberman 57(5):48-49.
See item 1324 above.

1326. Burgan, Robert E., and Robert E. Nelson.
1972. *Decline of ohia lehua forests in Hawaii.* USDA Forest Serv. Gen. Tech. Rep. PSW-3, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn.,

Berkeley, Calif.
The decline and death of large numbers of ohia trees can be attributed to a variety of agents, including fungus.

1327. Bynum, H. H., and D. R. Miller.
1964. *Elytroderma deformans found on knobcone pine in California.* Plant Dis. Rep. 48(10):828, illus.
A light infection on knobcone pine exhibited the same symptoms as on ponderosa pine.

1328. Bynum, H. H.
1965. *Effect of incense-cedar heartwood extractives on Polyporus amarus growth.* Mycologia 57(4):642-648.
Reports that growth of polyporus amarus in wood extract increased concentration up to a level of 2.27 mg/ml of extract, then fell off abruptly at higher concentrations.

1329. Ford, D. H., and T. E. Rawlins.
1956. *Improved cytochemical methods for differentiating Cronartium ribicola and Cronartium occidentale on Ribes.* Phytopathology 46(12):667-668.
Describes field method for differentiating between pinyon rust and white pine blister rust.

1330. Hawksworth, Frank G., Paul C. Lightle, and Robert F. Scharpf.
1968. *Arceuthobium in Baja California, Mexico.* Southwest Nat. 13(1):101-102.
Two dwarfmistletoes—*Arceuthobium campylopodum F. abietinum* (Engelm.) Gill and *A. campylopodum F. blumeri* (A. Nels.) Gill—probably do not grow in Baja California.

1331. Kimmey, James W.
1954. *Determining the age of blister rust infection on sugar pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 91, 4 p. Berkeley, Calif.
Demonstrates from California and Oregon data infection by white pine blister rust through needles is about twice as great in the Sierra Nevada as in Oregon.

1332. Kimmey, James W., and Paul C. Lightle.
1955. *Fungi associated with cull in redwood.* Forest Sci. 1:104-110, illus.
Two fungi, a brown cubical rot, most prevalent in the southern part of the tree's range, and a white ring rot, most severe in the northern part, cause virtually all cull due to decay.

1333. Kimmey, James W.
1955. *Rate of deterioration of fire-killed timber in California.* U.S. Dep. Agric. Circ. 962, 22 p., illus.
Gives rates of deterioration for five species and various sizes of trees, describes conditions influencing rate, names and evaluates the agents of deterioration, and discusses salvage problems.

1334. Kimmey, James W.
1957. *Dwarfmistletoes of California and their control.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 19, 12 p., illus. Berkeley, Calif.
Summarizes essential facts regarding the dwarfmistletoes and their control.

1335. Kimmey, James W.
1957. *A forest disease survey of Alaska.* The Plant Dis. Rep. Suppl. 247:87-98.
A brief summary of the general disease conditions found and a listing of fungi collected.

1336. Kimmey, James W.
1958. *The heart rots of redwood.* U.S. Dep. Agric. Forest Pest Leafl. 25, 7 p., illus.
Pictures and describes the two principal heart rots of redwood and lists the external indicators of their presence.

1337. Kimmey, James W., and H. H. Bynum, Jr.
1961. *Heart rots of red and white firs.* U.S. Dep. Agric. Forest Pest Leafl 52, 4 p., illus.
Principal fungi causing brown rot and white rot are discussed, and their method of entrance into the tree, the location of the rot column, and the indicators of rot are given.

1338. Kimmey, James W., and Willis W. Wagener.
1961. *Spread of white pine blister rust from ribes to sugar pine in California and Oregon.* U.S. Dep. Agric. Tech. Bull. 1251, 71 p., illus.
Describes conditions which are favorable to the spread of white pine blister rust.

1339. Laemmlen, Franklin, and Robert V. Bega.
1974. *Hosts of Armillaria mellea in Hawaii.* Plant Dis. Rep. 58(2):102-103.
Several new hosts of *Armillaria mellea* have been found in the state of Hawaii; most of the new hosts are on wildland plants.

1340. Lightle, Paul C.
1954. *The pathology of Elytroderma deformans on ponderosa pine.* Phytopathology 44(10):557-569.
Outlines the normal life cycle and reports investigations on the biology of the most important needle disease fungus on pines in the west.

1341. Lightle, Paul C.
1955. *Experiments on control of Elytroderma needle*

blight of pines by sprays. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 92, 6 p. Berkeley, Calif.

Possible reasons for the failure of applications of fungicidal sprays to control the disease are suggested.

1342. Lightle, Paul C.

1955. *Longevity of Peridermium harknessii aeciospores stored at 40° F.* Plant Dis. Rep. 39:983-984.

Aeciospores of this gall rust retained their viability when air dried prior to low temperature storage.

1343. McCain, Arthur H., and Richard S. Smith, Jr.

1972. *Quantitative assay of Macrophomina phaseoli from soil.* Phytopathology 62:1098.

A method for a quantitative assay directly from soil using both wet sieving and a selective medium has been developed.

1344. McCartney, William O., Robert F. Scharpf, and Frank G. Hawksworth.

1973. *Additional hosts of Viscum album, European mistletoe, in California.* Plant Dis. Rep. 57:904.

Records the occurrence of the European mistletoe on 12 more hosts, and two others as determined by inoculations.

1345. Miller, Douglas R., James W. Kimmey, and Marvin E. Fowler.

1959. *White pine blister rust.* U.S. Dep. Agric. Forest Pest Leafl. 36, 8 p., illus.

Summarizes 30 years of research and control experience on the distribution, life cycle, host symptoms, and methods of control.

1346. Miller, Douglas R., and H. H. Bynum.

1965. *Dwarfmistletoe found on foxtail pine in California.* Plant Dis. Rep. 49(8):647, illus.

Reports first collection of *A. campylopodum* Engel. f. *cyanocarpum (A. Nels.)* Gill on foxtail pine.

1347. Mirov, N. T.

1938. *Vegetative propagation of white pine as a possible method of blister rust control.* J. For. 36(8):807-808.

Points to successful experiments where cuttings from immune mother trees were rooted successfully as a simpler alternative to the parthenogenetic production of seeds for the development of a white pine strain immune to blister rust.

1348. Offord, Harold R., Clarence R. Quick, and V. D. Moss.

1958. *Blister rust control aided by the use of chemicals for killing ribes.* J. For. 56:12-18.

Factors affecting the use of 2,4-D and 2,4,5-T under forest conditions are given special emphasis.

1349. Offord, Harold R.

1960. *The chemical control of mistletoes.* Weed Soc. Am. Proc. Denver, Colorado, 1960. 5 p.

Reviews accomplishments in chemical control and suggests types of toxicants and methods of application that appear promising for control of dwarfmistletoes.

1350. Offord, Harold R.

1960. *New approaches to forest disease control by chemicals.* Proc. Fifth World For. Congr. Vol. 2, Seattle, Wash., 1960:882-887.

Intensified research in the use of systemic toxicants justified by recent successes in the nursery and in the managed forest suggests the possibilities of a 'package' approach to forest pest control.

1351. Offord, Harold R.

1961. *Forest diseases in California—problems and the research program of the Pacific Southwest Station.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 60, 29 p., illus.

Responsibilities and objectives are reviewed to show magnitude of losses caused by disease pests, statewide variations in climate in relation to the prevalence of heart rots, mistletoes, white pine blister rust, and root and foliage diseases.

1352. Offord, Harold R.

1964. *Diseases of Monterey pine in native stands of California and in plantations of Western North America.* U.S. Forest Serv. Res. Paper PSW-14, 37 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The prevalence and identity of 72 pathogens are summarized and interpreted against a brief background of the host and its environment.

1353. Offord, Harold R.

1964. *A new record of dwarfmistletoe on planted Monterey pine in California.* Plant Dis. Rep. 48(11):912.

The western dwarfmistletoe of hard pines commonly found in San Luis Obispo and Monterey Counties on native Monterey pine has been found for the first time in Alameda County on planted pine.

1354. Offord, Harold R.

1966. *Sequential sampling of ribes populations in the control of white pine blister rust (Cronartium ribicola) in California.* U.S. Forest Serv. Res. Paper PSW-36, 14 p., illus. Pacific Southwest

Forest and Range Exp. Stn., Berkeley, Calif.
In 9 to 13 comparison field trials the sequential method gave the same control decision as the regular line transect sampling method; in 4 trials, in which the 2 field procedures failed to agree on the control decision, each method was credited with 2 preferable decisions.

1355. Paine, Lee A., and William G. O'Regan.
1962. *Growth studies of regional isolates of Echinodontium tinctorium, the Indian paint fungus.* Can. J. Bot. 40:14-23, illus.
Effects of temperature and time on *in vitro* growth were described by polynomial approximations of the three-dimensional surfaces.

1356. Paine, Lee A., Gideon Schwarzbart, and William G. O'Regan.
1964. *Estimation of growth-time-temperature characteristics for isolates of a heart rot fungus, Fomes pini.* Can. J. Bot. 42(12):1635-1652.
Regression analysis techniques were applied to the estimation of three-dimensional surfaces representing the growth of *Fomes pini* as a function of time and temperature.

1357. Paine, Lee A.
1966. *Butt rot defect and potential hazard in lodgepole pine on selected California recreational areas.* U.S. Forest Serv. Res. Note PSW-106, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Within the areas sampled, potentially hazardous trees were common on recreational sites, with defect and decay correlated to fire damage.

1358. Parmeter, John R., Jr., Robert V. Bega, and J. R. Hood.
1960. *Epidemic leaf-blighting of California-laurel.* Plant Dis. Rep. 44:669-671, illus.
A 1957-58 outbreak in central California had its origin in two wet winters 1955-56 and 1957-58 with two fungi and one bacterium combining to cause the damage.

1359. Parmeter, John R., Jr., R. V. Bega, and T. Neff.
1962. *A chlorotic decline of ponderosa pine in southern California.* Plant Dis. Rep. 46:269-273.
Examination of roots, stems, and needles failed to disclose the consistent presence of pathogenic organisms and suggested drought, air pollution, or a combination of the two as possible causes.

1360. Parmeter, John R., Jr., and Robert F. Scharpf.
1963. *Dwarfmistletoe on red fir and white fir in California.* J. For. 61:371-374, illus.
Field observations and cross-inoculation studies show that there are two specialized forms of fir dwarfmistletoe, one attacking only red fir and one only white fir.

1361. Parmeter, John R., Jr., and Robert F. Scharpf.
1963. *Some characteristics of dwarfmistletoe populations on red fir.* Phytopathology 53:885.
Differences in fruiting and mortality among infections on trees from different areas suggest that different populations may vary in these respects.

1362. Parmeter, John R., Jr., and Robert F. Scharpf.
1972. *Spread of dwarf mistletoe from discrete seed sources into young stands of ponderosa and Jeffrey pines.* USDA Forest Serv. Res. Note PSW-268, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Infection was heaviest in generally northerly directions from seed sources and was correlated with prevailing winds and mistletoe seed dispersal patterns.

1363. Peterson, Glenn W., and Richard S. Smith, Jr.
1975. *Forest nursery diseases in the United States.* U.S. Dep. Agric., Agric. Handb. 470, 125 p., illus.
Discusses hosts, symptoms, damage, life cycles, distribution of pathogens, and methods for control of 32 diseases that infect seedlings.

1364. Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson.
1975. *Ohia forest decline, its spread and severity in Hawaii.* USDA Forest Serv. Res. Paper PSW-105, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Between 1954 and 1972, the number of acres of ohia and ohia-koa rain forest on the island of Hawaii with severe decline increased from 300 to 85,000.

1365. Quick, Clarence R.
1962. *Relation of canyon physiography to the incidence of blister rust in the central Sierra Nevada.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 67, 13 p. Berkeley, Calif.
A study of infection shows a marked correlation between canyon physiography and rust intensity and concludes that a records approach could be useful in planning control work.

1366. Quick, Clarence R.
1964. *Experimental fungicidal control of blister rust on sugar pine in California.* U.S. Forest Serv. Res. Note PSW-48, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Several antibiotic and conventional fungicides which

appeared slightly systemic proved more effective when sprayed directly, with large differences in effectiveness attributed to concentration and season of application.

1367. Quick, Clarence R.
1964. *Experimental herbicidal control of dwarfmistletoe on some California conifers.* U.S. Forest Serv. Res. Note PSW-47, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Results from spray applications of many phenoxy herbicides and some other materials showed that an isooctyl ester of 2,4,5-trichlorophenoxy butyric acid was the most promising herbicide tested for direct spray treatment.

1368. Quick, Clarence R.
1966. *Experimental inoculation of ponderosa pine with western gall rust.* Plant Dis. Rep. 50(8):550-552, illus.
Describes two methods for test inoculation of ponderosa pine infected with western gall rust.

1369. Quick, Clarence R.
1967. *Chemical control of blister rust on sugar pine . . . two fungicides show promise in California tests.* U.S. Forest Serv. Res. Note PSW-147, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Among several fungicides tested, Phytoactin L-340 and Dowicide 1 (0-phenylphenol) showed the most promise for systemic control.

1370. Quick, Clarence R., and Clifford N. Lamoureaux.
1966. *Field inoculation of white pine blister rust cankers on sugar pine with Tuberculina maxima.* Plant Dis. Rep. 51(2):89-90.
A simple field method is described for inoculation of blister rust cankers with purple mold spores.

1371. Quick, Clarence R.
1967. *Screening conventional fungicides . . . control of blister rust on sugar pine in California.* U.S. Forest Serv. Res. Note PSW-149, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
After five years, 4 of 14 fungicides tested showed varying promise of development into staisfactory direct control of blister rust but little promise of systemic control was found.

1372. Scharpf, Robert F., and John R. Parmeter, Jr.
1962. *Penetration of red fir by the dwarfmistletoe, Arceuthobium campylopodium.* Phytopathology 52(8):750.
The parasite mechanically penetrates branches generally at the point of needle attachment, and spreads within the living tissue by growing between cells and by crushing adjacent cells.

1373. Scharpf, Robert F.
1964. *Cultural variation and pathogenicity of the colletotrichum blight fungus of dwarfmistletoe.* Phytopathology 54(8):905-906.
Study describes the cultural differences among isolates of the fungus and discusses host affinities, determined from cross inoculation tests.

1374. Scharpf, Robert F.
1964. *Dwarfmistletoe on true firs in California.* U.S. Dep. Agric. Forest Pest Leafl. 89, 7 p., illus.
Included in the paper is general information on life history, damage, and silvicultural control.

1375. Scharpf, Robert F.
1964. *Epidemiology and parasitism of the dwarfmistletoe: Arceuthobium campylopodum Engleman, in California.* Diss. Abstr. 24(10):3922.
In general, dissemination of fir-infecting seeds began earlier in the fall and extended over a shorter period than it did with the seeds infecting Digger pine.

1376. Scharpf, Robert F., and John R. Parmeter, Jr.
1966. *Determining the age of dwarfmistletoe infections on red fir.* U.S. Forest Serv. Res. Note PSW-105, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Suggests that dwarfmistletoe can be aged rapidly and reliably by counting the number of annual rings showing swelling and then adding 1 year for the lag period between infection and swelling.

1377. Scharpf, Robert F., and Frank Hawksworth.
1966. *Hosts and distribution of Uredo phoradendri.* Mycologia 58(5):811-812.
Summarizes information on the rust on *Phoradendron* spp. in the United States, and reports it on a new host *P. bolleanum* ssp. *pauciflorum* (Torr.) Wiens, and for the first time in Mexico.

1378. Scharpf, Robert F., and John R. Parmeter, Jr.
1967. *The biology and pathology of dwarfmistletoe Arceuthobium campylopodum F. abietinum, parasitizing true firs (Abies spp.).* U.S. Dep. Agric. Tech. Bull. 1362, 42 p., illus.
Compares the behavior of dwarfmistletoes on red fir and white fir with that observed for other hosts, and helps clarify some disputed aspects of the biology and pathology of dwarfmistletoes.

1379. Scharpf, Robert F., and John R. Parmeter, Jr.
1967. *Spread of dwarfmistletoe to Jeffrey pine plantation . . . trees infected after 22 years.* U.S. Forest Serv. Res. Note PSW-141, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Dwarfmistletoe was able to spread from infected overstory ponderosa pine into planted Jeffrey pine a maximum distance of about 145 feet, infecting about one-third of the trees within this distance.

1380. Scharpf, Robert F., and Frank G. Hawksworth.
1968. *Dwarfmistletoe on sugar pine.* Forest Pest Leafl. 113, 4 p., illus.
Briefly describes the life history, symptoms and signs of infection, damage, and control of this parasite in California and Oregon.

1381. Scharpf, Robert F.
1969. *Cytospora abietis associated with dwarf mistletoe on true firs in California.* Phytopathology 59(11):1657-1658.
Geographic location and age of dwarf mistletoe were not important factors influencing infection by *C. abietis.*

1382. Scharpf, Robert F.
1969. *Dwarf mistletoe on red fir . . . infection and control in understory stands.* USDA Forest Serv. Res. Paper PSW-50, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Height of understory trees was found to be the most important factor related to both percentage of trees infected and intensity of infection.

1383. Scharpf, Robert F.
1969. *Temperature affects penetration and infection of pines by dwarfmistletoe.* Forest Sci. 15(2):149-151.
Temperature influenced penetration and infection of Digger pine and Monterey pine with no penetration or infection occurring at constant 27° C. or above.

1384. Scharpf, Robert F., John Staley, and F. G. Hawksworth.
1970. *A needle cast, the first known disease of bristlecone fir in California.* Plant Dis. Rep. 54(4):275-277, illus.
A fungus *(Lirula nervisequia* var. *Conspicua)* reported previously only on *Abies* in Europe and Asia is responsible for the first known disease of bristlecone fir in its native range in California.

1385. Scharpf, Robert F., and John R. Parmeter.
1971. *Seed production and dispersal by dwarfmistletoe in overstory Jeffrey pines in California.* USDA Forest Serv. Res. Note PSW-247, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Number of seeds trapped decreased at a logarithmic rate as distance from an overstory source of infection increased.

1386. Scharpf, Robert F.
1972. *Light affects penetration and infection of pines by dwarf mistletoe.* Phytopathology 62(11):1271-1273, illus.
The highest percentage infection of *Pinus sabiniana* occurred in full and half sunlight at near ambient temperatures.

1387. Scharpf, Robert F., and M. D. Srago.
1974. *Conifer damage and death associated with the use of highway deicing salt in the Lake Tahoe Basin of California and Nevada.* USDA Forest Serv. Calif. Reg. Forest Pest Control Tech. Rep. 1, 16 p., illus. Berkeley, Calif.
Salt applied to highways is a major cause of damage and death to roadside conifers in the Lake Tahoe Basin.

1388. Scharpf, Robert F., and F. G. Hawksworth.
1974. *Mistletoes on hardwoods in the United States.* Forest Pest Leafl. 147, 7 p., illus.
Summarizes information on the biology, uses, and control of mistletoes and the damage caused by these parasites.

1389. Scharpf, Robert F., and H. H. Bynum.
1975. *Cytospora canker of true firs.* Forest Pest Leafl. 146, 5 p., illus.
Discusses the biology, symptoms, and damage caused by *Cytospora abietis* on true firs in Western United States, and includes suggestions for control.

1390. Scharpf, Robert F., and William McCartney.
1975. *Viscum album in California—its introduction, establishment and spread.* Plant Dis. Rep. 59:257-262.
Introduced in the early 1900's, *Viscum album* occurs in 21 species in a 16-square-mile area of California; spread and buildup, hosts, and control measures are discussed.

1391. Schubert, Gilbert H.
1961. *Fungi associated with viability losses of sugar pine seed during cold storage.* Soc. Am. For. Proc. 1960:18-21.
Various fungi were found to destroy good seed within a few years.

1392. Smith, Richard S., Jr.
1964. *Effect of diurnal temperature fluctuations in linear growth rate of Macrophomina phaseoli in culture.* Phytopathology 54(7):849-852.
Results showed that large fluctuations at the higher mean temperatures reduced the growth rate whereas small fluctuations increased with the growth rate, which suggests that the use of constant temperature data for interpreting the activity of *M. phaseoli* is questionable.

1393. Smith, Richard S., Jr.
1964. *Effect of temperature fluctuation on the charcoal root disease of Pinus lambertiana.* Phytopathology 54:908-909.
Reports that soil temperature fluctuations effect the severity of the charcoal root disease.

1394. Smith, Richard S., Jr., and Robert V. Bega.
1964. *Macrophomina phaseoli in the forest tree nurseries of California.* Plant Dis. Rep. 48(3):206.
Since 1960, the charcoal root disease has been found in three previously reported hosts and six unreported coniferous hosts in a total of nine widely scattered nurseries in California.

1395. Smith, Richard S., Jr.
1965. *Pathogenicity of Verticicladiella wagenerii to Pinus spp.* Phytopathology 55(10):1077.
Describes a study to determine the pathogenicity of two isolates of *Verticicladiella wagenerii* Kend.—one from singleleaf pinyon pine and one from ponderosa pine.

1396. Smith, Richard S., Jr., Robert V. Bega, and Jerry Tarry.
1966. *Additional hosts of Fomes annosus in California.* Plant Dis. Rep. 50(3):181.
Fomes annosus was found attacking and killing five new hosts, *Pinus patula, Abies bracteata, Archtostaphyllos viscida, Archtostaphyllos manzanita,* and *Artemisia tridentata.*

1397. Smith, Richard S., Jr.
1966. *Effect of diurnal temperature fluctuations on the charcoal root disease of Pinus labertiana.* Phytopathology 56(1):61-64, illus.
Reports that both the daily mean temperature and the amplitude of diurnal temperature fluctuations influence the severity of the disease.

1398. Smith, Richard S., Jr.
1966. *Foliage disease control.* Proc. Tenth Bienn. West. Forest Nursery Counc. Meet. 1966:70-72, illus.
Suggests that there is more to controlling foliage diseases than just spraying; the choice of the fungicide and the proper timing of its application are of extreme importance.

1399. Smith, Richard S., Jr., and Robert V. Bega.
1966. *Root disease control by fumigation in forest nurseries.* Plant Dis. Rep. 50(4):245-248.
In control tests the fumigants gave better control than the fungicides.

1400. Smith, Richard S., Jr.
1966. *Rosellinia needle blight of Douglas-fir in California.* Plant Dis. Rep. 50(4):249-250, illus.
A needle blight of Douglas-fir, found in a northern California forest nursery, is reported for the first time in Western United States.

1401. Smith, Richard S., Jr., and Stanley L. Krugman.
1967. *Control of the charcoal root disease of white fir by fall soil fumigation.* Plant Dis. Rep. 21(8):671-674, illus.
The two fumigants tested appear to hold promise as a means of controlling charcoal root disease and producing disease-free white fir stock.

1402. Smith, Richard S., Jr.
1967. *Decline of Fusarium oxysporum in the roots of Pinus lambertiana seedlings transplanted into forest soils.* Phytopathology 57(11):1265.
After four years *Fusarium oxysporum*—a fungus which causes a root disease of pines in forest nurseries but which is not normally present in forest soils—had declined to the point where it was no longer detectable.

1403. Smith, Richard S., Jr.
1967. *Verticicladiella root disease of pines.* Phytopathology 57(9):935-938, illus.
Isolation of this disease from *Pinus monophylla* and *P. ponderosa* infected roots indicates that, even though the isolates are not host specific, they are geographically and morphologically different.

1404. Smith, Richard S., Jr.
1970. *Borax to control Fomes annosus infection of white fir stumps.* Plant Dis. Rep. 54(10):872-875.
All three borax treatments reduced infection significantly, but the dry powder application of borax was the most effective.

1405. Smith, Richard S., Jr., Arthur H. McCain, Michael D. Srago, R. F. Krohn, and D. Perry.
1972. *Control of Sirococcus tip blight of Jeffrey pine seedlings.* Plant Dis. Rep. 56(3):241-242.
In test plots, chlorothanlonil, captafol, and mancozeb

sprayed once every 2 weeks successfully controlled the tip blight of 2-year-old seedlings.

1406. Smith, Richard S., Jr.
1972. *Needleclasts of high-altitude white pines in California.* Plant Dis. Rep. 56(2):102-103, illus.
A new host and new region has been found for this pathogen in California's Sierra Nevada.

1407. Smith, Richard S., Arthur H. McCain, and Michael D. Srago.
1973. *Control of botrytis storage rot of giant sequoia seedlings.* Plant Dis. Rep. 57(1):67-69.
Among the four fungicides tested, benomyl—either as a prelifting field spray or a postlifting dip—gave excellent control.

1408. Smith, Richard S., Jr.
1973. *Sirococcus tip dieback of Pinus spp. in California forest nurseries.* Plant Dis. Rep. 57(1):69-73, illus.
Reports what is believed to be the first appearance of this disease in Western North America.

1409. Smith, Richard S., Jr.
1974. *Prospects for reducing forest damages from the black stain root disease caused by Verticicladiella wagenerii.* Calif. Plant Pathol. 19, 2 p.
The prospects for more effective control may depend on finding more about the establishment and spread of infection centers and about the effects forest management practices have on these centers.

1410. Smith, Richard S., Jr., and David Graham.
1975. *Black stain root disease of conifers.* Forest Pest Leafl. 145, 4 p., illus.
Caused by the fungus *Verticicladiella wagenerii* Kend., the black stain root disease is more widespread than earlier reports had suggested.

1411. Srivastava, L. M., and K. Esau.
1961. *Relation of dwarfmistletoe (Arceuthobium) to the xylem tissue of conifers. I. Anatomy of parasite sinkers and their connection with hose xylem.* J. Bot. 48(2):159-167.
Studies showed that the sinkers of arceuthobium were found to be composed of parenchyma cells only, or of parenchyma cells and tracheary elements, including vessel elements, and that in all species tracheary cells had direct contacts with the host tracheids of axial and radial systems.

1412. Srivastava, L. M., and K. Esau.
1961. *Relation of dwarfmistletoe (Arceuthobium) to the xylem tissue of conifers. II. Effect of the parasite on the xylem anatomy of the host.* J. Bot. 48(3):209-215.
Pronounced abnormalities in the xylem anatomy due to infection are observed in the shape and size of the infected rays which assume a hypertrophied appearance and fuse to form large composite rays.

1413. Toussoun, T. A., W. Menzinger, and R. S. Smith.
1969. *Role of litter on the ecology of Fusarium in conifer forest soils.* Phytopathology 59(10):1396-1399, illus.
The general absence of Fusarium could be attributed to germination of chlamydospores and destruction of germ tubes before new chlamydospores are formed.

1414. Toussoun, T. A., Robert V. Bega, and Paul E. Nelson, eds.
1970. *Root diseases and soil-borne pathogens.* 252 p., illus. Univ. Calif. Press, Berkeley, Calif.
Includes papers presented at the Second International Symposium on Factors Determining the Behavior of Plant Pathogens in Soil, London, England, 1968, held in conjunction with the First International Congress of Plant Pathology.

1415. U.S. Forest Serv., Pacific Southwest Forest and Range Experiment Station.
1958. *What's wrong with my trees?* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 26, 2 p., illus. Berkeley, Calif.
Describes symptoms and extent of spread of foliage diseases of hardwoods, chiefly the leaf blights of California laurel and the leaf spot fungus of black oak.

1416. Wagener, Willis W.
1954. *Heart rots in living trees.* The Bot. Rev. 20(2):61-134.
A comprehensive survey of the principal world literature on heart rots, embracing 345 titles.

1417. Wagener, Willis W.
1955. *Heart rots in living trees.* Natl. Shade Tree Conf. Proc. 1954:227-231.
Heartwood decaying fungi fall in two groups: true heart rotters, and fungi decaying primarily sapwood and dead limbs but that may also extend into heartwood.

1418. Wagener, Willis W.
1957. *The limitations of two leafy mistletoes of the genus Phoradendron by low temperatures.* Ecology 38(1):142-145.
Reports the killing of leafy mistletoes in western juniper and white fir by extreme cold thus supporting the idea that the distribution of these mistletoes is affected by low temperatures.

1419. Wagener, Willis W., and Robert V. Bega.
1958. *The heart rots of incense-cedar.* U.S. Dep. Agric. Forest Pest Leafl. 30, 7 p., illus.
Describes the principal heart rot and other rots of the species.

1420. Wagener, Willis W.
1959. *The effect of a western needle fungus (Hypodermella medusa Dearn.) on pines and its significance in forest management.* J. For. 57(8):561-564.
Plot studies and 30 year's general observations show that this disease on ponderosa and Jeffrey pine does not constitute a major loss factor.

1421. Wagener, Willis W.
1961. *The influence of light on establishment and growth of dwarfmistletoe on ponderosa and Jeffrey pines.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 181, 5 p. Berkeley, Calif.
Observations indicate that former ideas concerning the beneficial effects of ample sunlight on establishment and development of the parasite may be inaccurate.

1422. Wagener, Willis W., and James L. Mielke.
1961. *A staining-fungus root disease of ponderosa, Jeffrey, and pinyon pines.* Plant Dis. Rep. 45(11):831-835, illus.
Describes growth and spread of a killing root disease which seems to represent a new type of fungus in forest tree pathogens.

1423. Wagener, Willis W.
1964. *Diseases of Cupressus.* In *Diseases of widely planted forest trees.* FAO/FORPEST 64, p. 17-24.
Lists and discusses the diseases of *Cupressus.*

1424. Wagener, Willis W.
1964. *"Facultative heteroecism." Was it demonstrated in Peridermium Harkenssii in 1919-20?* Mycologia 56(5):782, 785.
An examination of Meineke's original records suggests that a dual capability for autoecism and heteroecism was not demonstrated.

1425. Wagener, Willis W.
1965. *Dwarfmistletoe removal and reinvasion in Jeffrey and ponderosa pine, northeastern California.* U.S. Forest Serv. Res. Note PSW-73, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Ten years of annual removal of infections and prevention of seeding of dwarfmistletoe from a young mixed pine stand failed to completely eliminate the parasite from an experimental plot.

1426. Wagener, Willis W.
1967. *Red band needle blight of pines . . . a tentative appraisal for California.* U.S. Forest Serv. Res. Note PSW-153, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Red band needle blight—a world-wide disease attacking about 30 pine species—has been found killing Monterey and other pines in California's northwest coastal counties.

1427. Watanabe, Tsuneo, Richard S. Smith, and William C. Snyder.
1970. *Populations of Macrophomina phaseoli in soil as affected by fumigation and cropping.* Phytopathology 60:1717-1719.
Populations, greatly reduced by soil fumigation, increased slightly in fallow soils or soils cropped to ponderosa pine and moderately in soils cropped to white fir.

1428. Wear, John F.
1970. *Developing remote sensing techniques for diseased trees.* J. Remote Sensing 1(5):6-10, 17, illus.
Describes an aerial sampling system that collates a nonimaging thermal radiometer with an electronic vidicon camera system.

1429. Wickman, Boyd E., and Robert F. Scharpf.
1972. *Decay in white fir top-killed by Douglas-fir tussock moth.* USDA Forest Serv. Res. Paper PNW-133, 9 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.
No decay resulting in cull occurred in trees top-killed by Douglas-fir tussock moth, and only one tree top-killed by fir engraver beetles contained decay which resulted in cull.

Insecticide Evaluation

1430. Andrews, Theresa L., and Raymond P. Miskus.
1968. *Tetraethylammonium chloride as a potential antidote for some insecticidal carbamates and nicotine in mice.* Science 159:1367-1368.
Tetraethylammonium chloride (TEA) and atropine sulfate offered equal protection against lethal oral doses of several insecticides tested with TEA producing none of atropine sulfate's undesirable reactions.

1431. Andrews, Theresa L., and Raymond P. Miskus.
1972. *Some effects of fatty acids and oils on western spruce budworm larvae and pupae.* Pestic. Biochem. and Physiol. 2(3):257-261.
Levels of glucose-6-phosphate, N-acetylglucosamine and hexokinase were unchanged in larvae, and were below detectable limits in pupae.

1432. Andrews, Theresa L.
1974. *Resmethrin residues in foliage after aerial application.* Pestic. Monit. J. 8(1):50-52.
The residue on the aspen and Douglas-fir showed that the initial deposit was light, and no detectable residue was present after 7 days.

1433. Buffam, Paul E., and Norman E. Johnson.
1966. *Tests of guthion and dimethoate for Douglas-fir cone midge control.* Forest Sci. 12(2):160-163.
Finds that significantly fewer midges, less midge damage, and fewer seed chalcids were observed in cones from trees given the late dimethoate treatment when compared to controls.

1434. Buffam, Paul E., Hubert E. Meyer, and Raymond P. Miskus.
1967. *Small-scale trials of five insecticides . . . sprayed on spruce budworm in Montana.* U.S. Forest Serv. Res. Note PSW-159, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Among five insecticides tested, low-volume Zectran was as effective as malathion, LVC, and DDT, and similar results were obtained with SD-8530 formulations with and without synergist.

1435. Crisp, Carl E.
1972. *The molecular design of systemic insecticides and organic functional groups in translocation.* In *Pesticide chemistry.* Vol. I—Insecticides. p. 211-263, illus. A. S. Tahori, ed. Gordon and Breach, London.
Reports development of a new approach to understanding symplastic (phloem mobile) and apoplastic (xylem mobile) systemic insecticides.

1436. Downing, G. L.
1954. *Ethylene dibromide sprays for controlling bark beetles in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 17, 2 p. Berkeley, Calif.
Outlines procedure for using penetrating oil sprays.

1437. Eaton, Charles B.
1964. *Helicopter spraying to control forest insects.* Rep. Fourth Agric. Aviat. Res. Conf. p. 27-31. U.S. Dep. Agric., Agric. Res. Serv.
Aerial sprays have been successful against defoliating insects, but have been ineffective against bark beetles until recent improvements in helicopters and greater control over spray distribution.

1438. Flake, Harold W., and Robert L. Lyon.
1967. *Insecticide tests against larvae of Hemerocampa, new species, a tussock moth that defoliates boxelder in New Mexico.* J. Econ. Entomol. 60(2):607-608.
The decreasing order of effectiveness was pyrethrins, Zectran, DDT, DS-8530, carbaryl, and malathion.

1439. Greene, Lula E., and M. Page.
1974. *Oak leaf roller, contact toxicity of four insecticides applied to the larvae.* USDA Forest Serv. Res. Note PSW-291, 2 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
All four insecticides tested—bioethanomethrin, pyrethrins, mexacarbate, and phoxim—caused 90 percent kill with less than 1 microgram per insect.

1440. Himel, Chester M., Leland Vaughn, Raymond P. Miskus, and Arthur D. Moore.
1965. *A new method for spray deposit assessment.* U.S. Forest Serv. Res. Note PSW-87, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Solid fluorescent particles sized to 1-3 microns, suspended in a spray liquid, are the basis of a new method for the visual recognition of the size and number of droplets impinging on target and non-target portions of sprayed areas.

1441. Himel, Chester M., and Arthur D. Moore.
1967. *Spruce budworm mortality as a function of aerial spray droplet size.* Science 156(3779):1250-1251.
A test which determines the size and number of drops impinging on spruce budworm in its conifer forest habitat using fluorescent particles in a liquid spray found no evidence that significant numbers of drops larger than 100μ reached the target insects.

1442. Jackson, Willard L.
1960. *A trial of direct control of pine engraver beetles on a small logging unit.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 44, 7 p., illus. Berkeley, Calif.
Results from an application of lindane applied to heavily infested slash showed that although outbreaks followed logging on other similar sites, only one pole-sized tree was killed in the 39-acre unit treated.

1443. Koerber, Thomas W.
1963. *Insecticide tests on the Douglas-fir cone midge,*

Contarinia oregonensis Foote. Can. Entomol. 95(6):640-645, illus.
Of three insecticides—lindane, dieldrin, and Sevin—applied to infested duff samples, lindane was most effective.

1444. Koerber, Thomas W.
1963. *The toxicity of diesel oil to Douglas-fir cones.* U.S. Forest Serv. Res. Note PSW-6, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Applications of diesel oil exceeding 5 gallons per acre killed young cones and possibly reduced seed quality in surviving cones.

1445. Lang, Jean M., and Raymond P. Miskus.
1967. *Zectran fed orally to mice . . . cholinesterase levels in blood determined.* U.S. Forest Serv. Res. Note PSW-140, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The cholinesterase levels in mouse blood were determined as a function of Zectran feeding and time.

1446. Lang, Jean M.
1969. *Effects of regurgitation and reflex bleeding on mortality of budworm (Choristoneura occidentalis) treated with lannate.* Entomol. Exp. and Appl. 12(3):288-296, illus.
After treatment, larvae showed symptoms of hyperactivity, regurgitation, and reflex bleeding, resulting in increased mortality.

1447. Lang, Jean M.
1970. *Reduction in the fertility of female Choristoneura occidentalis by lannate.* J. Econ. Entomol. 63(5):1619-1921.
A low dose topically applied to sixth-instar larvae caused hyperactivity, regurgitation, bleeding and prostration in 98 percent, while killing only 27 percent.

1448. Larson, John E., G. R. Pieper, and H. Ratsch.
1967. *Systemic activity of Zectran, Matacil, Bidrin injected into conifer trunks.* Pestic. Monit. J. 1(2):49-53, illus.
In small Douglas-fir, injection of each insecticide at rates of 40 to 200 mg per tree resulted in high mortality of spruce budworm, but in larger trees, only Matacil and Bidrin injections—at rates of 0.2 to 1 g per tree—resulted in mortality.

1449. Look, Melvin.
1968. *Synthesis of N-acetyl-l-C-Zectran (4-dimethylamino-3, 5-xylyl-N-actetyl-l'-C methylcarbamate) by mictroacetylation.* J. Agric. and Food Chem. 16(6):893.

1450. Look, Melvin, and Larry R. White.
1972. *Synthesis of 2-acyl-3-amino-1,2,4-triazoles and 2-acetyl-3-amino-1,2,4-triazole-5-^{14}C.* J. Agric. and Food Chem. 20(4):824.
Acylation of amitrole (3-amino-1,2,3-triazole)with N-acyl imidazole gave 1-acyl amitrole exclusively, whereas previous methods using acyl halides or anhydrides yielded mixtures of acylated and diacylated derivatives.

1451. Lyon, Robert L.
1959. *Lindane—a better insecticide for pine engravers.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 29, 2 p., illus.
Laboratory tests show that lindane spray is a good bet for less costly control of certain bark beetles.

1452. Lyon, Robert L.
1959. *Tests with DDT foliar sprays to control the California flatheaded borer.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 152, 6 p. Berkeley, Calif.
Tests showed that satisfactory control is possible but not practical because very large amounts of DDT must be applied.

1453. Lyon, Robert L.
1959. *Toxicity of several residual-type insecticides to selected western bark beetles.* J. Econ. Entomol. 52(2):323-327.
An analysis of toxicity through topical application to the sexes of *D. brevicomis* and *D. monticolae* showed only two insecticides significantly more toxic to one of the sexes.

1454. Lyon, Robert L.
1960. *Directions for using lindane sprays to control Ips beetles in California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 33, 8 p. Berkeley, Calif.
Ips beetles can be controlled by the use of a 0.2 percent of lindane in diesel oil when applied according to directions in this report.

1455. Lyon, Robert L., and Boyd E. Wickman.
1960. *Mortality of the western pine beetle and California five-spined Ips in a field trial of lindane.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 166, 7 p., illus. Berkeley, Calif.
A spray of 1.5 percent lindane in diesel oil applied to infested ponderosa pine killed 100 percent of the emerging engraver beetles and 92 percent of the western pine beetles.

1456. Lyon, Robert L., and Richard W. Bushing.
1961. *The construction and performance of a portable,*

precision spray chamber. Can. Entomol. 93(9):785-794, illus.
This research tool delivers accurate, repeatable spray deposits which can be varied by modifying nozzle orifice, liquid pressure, or shutter opening time.

1457. Lyon, Robert L.
1965. *Forest insect control.* In *Problems in the development of tailor made insecticides—a symposium.* Entomol. Soc. Am. Bull. 11(2):71-77.
Summarizes work being done to develop large-scale measures for the control of bark beetles and defoliators.

1458. Lyon, Robert L.
1965. *Structure and toxicity of insecticide deposits for control of bark beetles.* U.S. Dep. Agric. Tech. Bull. 1343, 59 p., illus.
The solvent, concentration of insecticide, and amount of spray applied may greatly alter the form of the crystal deposit and affect other properties such as crystal density and coverage.

1459. Lyon, Robert L., and Patrick J. Shea.
1967. *Chemosterilants to control bark beetles . . . tepa shows promise in preliminary study.* U.S. Forest Serv. Res. Note PSW-139, 5 p., illus. Berkeley, Calif.
Use of a chemosterilant and the male sex pheromone jointly to attract and sterilize field populations shows promise as a control measure.

1460. Lyon, Robert L., Sylvia J. Brown, and Charles E. Richmond.
1967. *Insecticides tested on new tussock moth . . . defoliator found in Montana.* U.S. Forest Serv. Res. Note PSW-161, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Contact toxicity, in descending order was, pyrethrins, Zectran, malathion, DDT, SD-8530, and carbaryl.

1461. Lyon, Robert L., and Kenneth M. Swain.
1968. *Field test of lindane against overwintering broods of the western pine beetle.* USDA Forest Serv. Res. Note PSW-176, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Broods of western pine beetle, mountain pine beetle, California five-spined Ips, and perhaps other California species of bark beetles may be destroyed effectively by 1.5 percent lindane sprays applied at any time of the year.

1462. Lyon, Robert L., Marion Page, and Sylvia Brown.
1968. *Tolerance of spruce budworm to malathion . . . Montana, New Mexico populations show no differences.* USDA Forest Serv. Res. Note PSW-173, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Laboratory tests with malathion by topical aerosol application to 6th-instar spruce budworm showed no difference in the susceptibility of populations from Montana and New Mexico.

1463. Lyon, Robert L.
1969. *Formulation and structure of residual insecticides for bark beetle control.* Adv. in Chem. Ser. 86:192-206, illus.
The contact toxicity and deposit structure of surface deposits of the insecticides DDT, dieldrin, dinitrocresol, endrin, heptachlor, and lindane were studied in the laboratory on fiberboard panels.

1464. Lyon, Robert L., and Sylvia J. Brown.
1970. *Contact toxicity of insecticides applied to the fall cankerworm reared on an artificial diet.* J. Econ. Entomol. 63(6):1970-1971.
Among six insecticides tested by topical application, the pyrethrins were the most toxic at LD_{50} and LD_{90}.

1465. Lyon, Robert L., Harold W. Flake, and Linda Ball.
1970. *Laboratory tests of 55 insecticides on Douglas-fir tussock moth larvae.* J. Econ. Entomol. 63(2):513-518, illus.
The 10 most active insecticides tested in descending order of average toxicity of LD_{90} were pyrethrins, Dursban, Zectran, dichlorvos, GC 6506, Matacil, Neopynamin, allethrin, Bayer 37289, and DDT.

1466. Lyon, Robert L., and Margaret E. May.
1970. *Toxicity of aerosols to larch casebearer larvae.* USDA Forest Serv. Res. Note PSW-208, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Six insecticides were screened as aerosols, and their toxicity by both direct contact and residual contact on filter paper studied.

1467. Lyon, Robert L., and Sylvia J. Brown.
1971. *Contact toxicity of 14 insecticides tested on pine butterfly larvae.* USDA Forest Serv. Res. Note PSW-257, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
All 14 insecticides tested except trichlorfon were more toxic than DDT; SBP-1382, a synthetic pyrethroid, was the most toxic.

1468. Lyon, Robert L.
1971. *Contact toxicity of 17 insecticides applied topically to adult bark beetles.* USDA Forest Serv.

Res. Note PSW-249, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Five compounds—Zectran, Dursban, malathion, dichlorvos, pyrethrins—show promise for study as possible alternatives to lindane, which is now used for bark beetle supression.

1469. Lyon, Robert L.
1971. *Contact toxicity of 40 insecticides tested on pandora moth larvae.* USDA Forest Serv. Res. Note PSW-235, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Twenty-one insecticides were more toxic at LD_{90} than the standard, p,p'-DDT; 10 exceeded DDT in toxicity by 10 or more times.

1470. Lyon, Robert L., and Marion Page.
1971. *Toxicity of insecticide aerosols to needle miner adults of the genus Coleotechnites.* USDA Forest Serv. Res. Note PSW-243, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Pyrethrins were the most toxic insecticide tested; they were about 6 to 7 times more toxic than malathion, the insecticide now suggested for use in suppression of needle miner epidemics.

1471. Lyon, Robert L., and Jacqueline L. Robertson.
1971. *Toxicity of stabilized and unstabilized pyrethrins applied to western spruce budworm.* USDA Forest Serv. Res. Note PSW-255, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Concludes that stabilizers had no effect on basic contact toxicity.

1472. Lyon, Robert L., Sylvia J. Brown, and Jacqueline L. Robertson.
1972. *Contact toxicity of sixteen insecticides applied to forest tent caterpillars reared on artificial diet.* J. Econ. Entomol. 65(3):928-930, illus.
All insecticides tested equaled or exceeded DDT in toxicity; pyrethrins were 105 times more toxic than DDT.

1473. Lyon, Robert L., and Harry W. Camp.
1972. *The Forest Service's insecticide evaluation program.* In *Permanent association committees proceedings.* p. 48-50. West. For. and Conserv. Assoc., Portland, Oreg.
Summarizes progress since 1970 in the search for insecticides that are selective in action, low hazard to associated insects, short-lived, and generally harmless to the total environment.

1474. Menn, J. J., and R. P. Miskus.
1967. *Principles of pesticide metabolism studies.* In *Analytical methods for pesticides, plant growth regulators, and food additives,* Vol. V. p. 115-145, illus. Gunter Zweig, ed. Academic Press, New York.
Describes principles and suggests guidelines to be followed in planning metabolic studies in animals, plants, soils, air and water.

1475. Miskus, Raymond P., Deanna P. Blair, and John E. Casida.
1965. *Conversion of DDT to DDD by bovine rumen fluid, lake water, and reduced porpyrins.* J. Agric. and Food Chem. 13(5):481-483.
Studies with C^{14}-DDT incubated with bovine rumen fluid, lake water, and aqueous solutions of reduced prophyrins showed partial conversion to C^{14}-DDD which appears to persist for unusually long periods.

1476. Miskus, Raymond P., Melvin Look, Theresa L. Andrews, and Robert L. Lyon.
1968. *Biological activity as an effect of structural changes in Aryl N-methyl carbamates.* J. Agric. and Food Chem. 16(4):605-607.
In a test of biological activity of several carbamates on spruce budworm and on mice, the structure showing greatest activity was a 4-amino,3,5,di-alkyl ring substituted N-methlycarbamate.

1477. Miskus, Raymond P., Theresa L. Andrews, and Melvin Look.
1968. *Metabolic pathways affecting toxicity of N-acetyl Zectran.* J. Agric. and Food Chem. 17(4):842-844, illus.
N-acetylation of the insecticide Zectran does not greatly alter its toxic effects on spruce budworm, but virtually eliminates toxicity for mice.

1478. Miskus, Raymond P.
1969. *Report of the insecticide evaluation project, 1969.* Proc. Annu. Meet. West. Forest Pest Comm. Spokane, Washington 1969:30-33.
Describes the work of the evaluation unit at the Pacific Southwest Forest and Range Experiment Station, and the changes being made in focus and emphasis.

1479. Miskus, Raymond P., and Theresa L. Andrews.
1972. *Stabilization of thin films of pyrethrins and allethrin.* J. Agric. and Food Chem. 20(2):313-315.
The combination of an antioxidant and an ultraviolet screening agent in a mineral oil formulation can significantly stabilize pyrethroids for 4 hours.

1480. Miskus, Raymond P., and Robert L. Lyon.
1973. *Pyrethrum for control of forest insect pests.* In *Pyrethrum, the natural insecticide,* p. 281-290, John

E. Casida, ed. Academic Press, New York.
Summarizes work in the stabilization and application of pyrethrins for the control of the spruce budworm, western hemlock looper, Douglas-fir tussock moth, and forest tent caterpillar.

1481. Moore, Arthur D.
1957. *The relative toxicity of DDT, toxaphene, lindane, and isodrin to Dendroctonus brevicomis Lec. and Ips confusus (Lec.)* J. Econ. Entomol. 50(5): 548-550, illus.
A screening procedure was developed and tests conducted with four insecticides to rate their toxicity to the western pine beetle and the California five-spined engraver.

1482. Moore, Arthur D.
1965. *Progress of insecticide screening in forestry. Part II—Insecticide Evaluation Project.* Proc. West. Forest Pest Comm., Western For. and Conserv. Assoc. 1965:7-8.
Describes the purpose, organization, and work to date of the Chemical Insecticide Research and Development Project activated in 1964 at the Pacific Southwest Station.

1483. Moore, Arthur D.
1966. *Progress of insecticide evaluation research.* Proc. Annu. Meet. West. Forest Pest Comm. 1965:13-14, illus.
Summarizes advancement in the search for less persistent, more specific chemicals and reports development of a new method for assessing spray distribution.

1484. Moore, Arthur D.
1967. *Aircraft in forest insect control.* Aerial Appl. Short Course Proc., 16 p., illus. Univ. Calif., Berkeley.
Since the late 1940's, aircraft have been used to conduct surveys to detect and appraise insect outbreaks, to disseminate insect pathogens, and to apply insecticides.

1485. Moore, Arthur D.
1967. *Insecticide evaluation research by the U.S. Forest Service.* In *A report on forests, pests, and pesticides.* p. 28-29, illus. State Board of For., Sacramento, Calif.
Summarizes progress to date on research on finding less-persistent, more-specific chemicals and on developing methods of application that will reduce environmental contamination.

1486. Moore, Arthur D.
1969. *New developments in forest insect problems.* Trans. 34th North Am. Wildlife and Nat. Resour. Conf. 1969:155-159.
Summarizes progress on attempts to find suitable alternatives to conventional insecticides, and attempts to increase the efficiency and selectivity of chemicals used.

1487. Page, Marion, and Robert L. Lyon.
1973. *Insecticides applied to western tussock moth reared on artificial diet: laboratory tests.* J. Econ. Entomol. 66(1):53-55, illus.
The pyrethroids were the most toxic among the 18 insecticides tested.

1488. Page, Marion, and Robert L. Lyon.
1973. *Toxicity of eight insecticides applied to the western tent caterpillar.* J. Econ. Entomol. 66(4):995-997, illus.
Among the seven insecticides tested, resmethrin was 1262 times more toxic than DDT at LD_{90}.

1489. Page, Marion, Robert L. Lyon, and Lula E. Greene.
1974. *Contact toxicity of eleven insecticides applied to the spring cankerworm.* J. Econ. Entomol. 67(3):460-461.
In order of decreasing toxicity, five insecticides, bioethanomethrin, pyrethrins, phoxim, and mexacarbate, were more toxic than the standard carbaryl at both LD_{50} and LD_{90}.

1490. Parker, Louise.
1972. *New work for an ancient insecticide.* Agrichem. Age 15(1):6, 8, 10, illus.
Pyrethrins show considerable promise as one of the best potential substitutes for DDT in controlling destructive forest insects.

1491. Pieper, G. R., and R. P. Miskus.
1967. *Determination of Zectran residues in aerial forest spraying.* J. Agric. and Food Chem. 15(5):915-916.
Residue levels of the insecticide—followed over a period of 4 weeks—showed a rapid initial decline.

1492. Pieper, G. R.
1972. *Effect of target size and air movement on drop impingement efficiency and drop size distribution.* J. Econ. Entomol. 65(3):881-886, illus.
The use of large cards for drop collection in the field under wind conditions may lead to false conclusions as to the effectiveness of an insecticide spray coverage.

1493. Roberts, R. B., C. K. Duckles, Raymond P. Miskus, and T. T. Sakai.
1969. *In vivo fate of the insecticide Zectran in spruce budworm, tobacco budworm housefly larvae.* J. Agric. and Food Chem. 17(1):107-111, illus.
After topical application on test insects, Zectran was

degraded to at least 9 products in the tobacco and spruce budworm larvae, and to 10 products in the housefly larvae.

1494. Roberts, R. B., Robert L. Lyon, Marion Page, and Raymond P. Miskus.
1971. *Laser holography: its application to the study of insecticide particles.* J. Econ. Entomol. 64(2):533-536, illus.

Use of laser holography allows three-dimensional examination and step-action study of spray particles as they impinge on a substrate.

1495. Roberts, R. B., Robert L. Lyon, C. K. Duckles, and Melvin Look.
1972. *Influence of selected synergists on the action of five insecticides on larval western spruce budworm: absence of synergism and in vitro oxidation of Zectran.* J. Econ. Entomol. 65(5):1277-1282.

Zectran pyrethrins, and SD-9077 were not synergized by any of the common synergists; carbaryl was synergized by 4 of 22, and Landrin by 6 of 23 synergists tested.

1496. Robertson, Jacqueline L., Robert L. Lyon, Fay L. Shon, and Nancy L. Gillette.
1972. *Contact toxicity of twenty insecticides applied to Summerista canicosta.* J. Econ. Entomol. 65(6):1560-1562.

Four of 20 insecticides tested exceeded DDT in toxicity at LD_{50}, but only one—resmethrin—was significantly more toxic.

1497. Robertson, Jacqueline L.
1972. *Toxicity of Zectran aerosol to the California oakworm, a primary parasite, and a hyperparasite.* Environ. Entomol. 1(1):115-117, illus.

The descending order of tolerance at LD_{50} was: 5th, 4th, 3rd, 2nd, and 1st stage.

1498. Robertson, Jacqueline L., and Robert L. Lyon.
1973. *Douglas-fir tussock moth, contact toxicity of 20 insecticides applied to the larvae.* J. Econ. Entomol. 66(6):1255-1257.

Eleven of the 20 insecticides tested were more toxic than the standard, mexacarbate (Zectran), at both LD_{50} and LD_{90}, four formulations of pyrethrins tested showed no significant difference in toxicity.

1499. Robertson, Jacqueline L., and Robert L. Lyon.
1973. *Elm spanworm, contact toxicity of ten insecticides applied to the larvae.* J. Econ. Entomol. 66(3):627-628.

Ten insecticides representing four chemical groups were tested against *Ennomos subsignarius* (Hũber).

1500. Robertson, Jacqueline L., Robert L. Lyon, Fay L. Shon, and Marion Page.
1973. *Western blackheaded budworm, toxicity of five insecticides to two populations.* J. Econ. Entomol. 66(1):274-275.

The two populations—one from Alaska, the other from Washington—showed different responses to the five insecticides tested.

1501. Robertson, Jacqueline L., and Robert L. Lyon.
1973. *Western spruce budworm, non-resistance to Zectran.* J. Econ. Entomol. 66(3):801-802.

Budworm originating from a laboratory colony exposed to Zectran for 14 successive generations showed no trend toward increased tolerance to the insecticide.

1502. Robertson, Jacqueline L., and Nancy L. Gillette.
1973. *Western tent caterpillar: contact toxicity of ten insecticides applied to the larvae.* J. Econ. Entomol. 66(3):629-630.

Among the 10 insecticides tested, only two—-pyrethroids and resmethrin—were more toxic than $DDT_{pp'}$ at LD_{50}.

1503. Robertson, Jacqueline L., Marion Page, and Nancy L. Gillette.
1974. *Calocalpe undulata (L.): contact toxicity of ten insecticides to the larvae.* J. Econ. Entomol. 67(6):706-708.

The decreasing order of toxicity at LD_{50} of insecticides tested was, bioethanomethrin, phenothrin, pyrethrins, phoxim, tetrachlorvinfos, mexacarbate, carbaryl, phosmet, DDT, and malathion.

1504. Robertson, Jacqueline L., Robert L. Lyon, and Nancy L. Gillette.
1975. *Contact toxicity of 38 insecticides to pales weevil adults.* J. Econ. Entomol. 68(1):124-126.

Nine of the 38 insecticides tested were more toxic at the LD_{50} than aldrin—the chemical currently recommended for control.

1505. Robertson, Jacqueline L., Robert L. Lyon, and Marion Page.
1975. *Toxicity of selected insecticides applied to two defoliators of western hemlock.* J. Econ. Entomol. 68(2):193-196.

Reports results of 13 insecticides tested in a spray chamber against the 4th and 5th instars of the hemlock sawfly and the western hemlock looper.

1506. Schwartz, Jacqueline L., and Robert L. Lyon.
1970. *Laboratory culture of Orange Tortrix, and its susceptibility to four insecticides.* J. Econ. Entomol. 63(6):1788-1790, illus.

A convenient method for rearing large numbers of Orange Tortrix on an artificial diet is described.

1507. Schwartz, Jacqueline L., and Robert L. Lyon.
1971. *Contact toxicity of five insecticides to California oakworm, phryganidia californica Packard, reared on an artificial diet.* J. Econ. Entomol. 64(1):146-148, illus.

The decreasing order of toxicity at LD_{50} was: pyrethrins, Zectran, p,p'-DDT, carbaryl and malathion.

1508. Schwartz, Jacqueline L.
1971. *Inhibition of nerve cord metamorphosis in the western spruce budworm Choristoneura occidentalis Freeman (Lepidoptera: Tortricidae) by juvenile hormone analoges.* Gen. and Comparative Endocrinol. 17(2):293-299, illus.

Juvenile hormone mimic inhibited both shortening of interganglionic connectives and the fusion of ganglia.

1509. Sharp, Robert H., and Robert E. Stevens.
1962. *New techniques for spraying standing trees infested with bark beetles.* J. For. 60(8):548-550, illus.

Describes a portable pump and extension tubes for spraying up to 40 feet high on the boles of standing trees.

1510. Smith, Richard F.
1971. *Juveno-mimetic effects of Lannate in sublethal doses on western spruce budworm (Choristoneura occidentalis).* J. Invertebr. Pathol. 17(1):132-133.

In sublethal concentrations Lannate has weakly juveno-mimetic effects, but at higher concentrations, these effects are masked by the toxic properties that Lannate shares with other carbamate pesticides.

1511. Smith, Richard H.
1956. *Lyctus powder-post beetle control by surface application of oil preparations and solvents.* Pest Control 24(4):42-45, illus.

Describes several control methods, of which trichlorobenzene and velsicol AR-50 were significantly more effective than other preparations.

1512. Smith, Richard H.
1958. *Control of the turpentine beetle in naval stores stands by spraying attacked trees with benzene hexachloride.* J. For. 56(3):190-194, illus.

One percent BHC gamma isomer solution in diesel oil or No. 2 fuel oil, sprayed on recently attacked trees, proved satisfactory for controlling the black turpentine beetle.

1513. Smith, Richard H.
1967. *Lindane in diesel oil prevents western pine beetle (Dendroctonus brevicomis Leconte) attacks for at least one year.* J. Econ. Entomol. 60(6):1746-1747, illus.

A 2.5 percent solution was able to prevent attacks on ponderosa pine for one year, whereas on freshly attacked trees 2.5 percent aqueous emulsion stopped the attacks and prevented additional ones for at least two months.

1514. Smith, Richard H.
1970. *Length of effectiveness of Lindane against attacks by Dendroctonus brevicomis and D ponderosae in California.* J. Econ. Entomol. 63(4):1180-1181.

As a 2 percent oil solution spray, Lindane prevented attack for 36 months; as a 2 percent aqueous emulsion, it was effective for 22 months.

1515. Stevens, Robert E.
1957. *Ethylene dibromide emulsion spray for control of the mountain pine beetle in lodgepole pine.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 122, 3 p. Berkeley, Calif.

A water-emulsion spray of ethylene dibromide, which is cheaper and less hazardous than oil sprays or burning techniques, has been found effective for control.

1516. Stevens, Robert E.
1959. *Ethylene dibromide sprays for controlling bark beetles.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 147, 6 p., illus. Berkeley, Calif.

Summarizes information on the formulation and use of ethylene dibromide sprays and recommends two different formulations, an oil spray and a water emulsion spray.

1517. Stevens, Robert E.
1965. *DDT spray for control of the ponderosa pine tip moth (Rhyacionia zozana* [Kearfott]). U.S. Forest Serv. Res. Note PSW-57, 3 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A water emulsion spray applied by hand sprayer to young trees infested with eggs and early-instar larvae stopped further larval activity and effectively prevented all damage.

1518. Stevens, Robert E.
1966. *Malathion aerial spray controls the pine needle-sheath miner.* U.S. Forest Serv. Res. Note PSW-102, 2 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A spray, applied by helicopter at the rate of 1 lb. of insecticide in 25 gallons of water, was an effective control.

1519. Struble, George R.
1965. *Effect of aerial sprays on parasites of the*

lodgepole needle miner. J. Econ. Entomol. 58(2):226-227.
Helicopter sprays of malathion in 1959 and 1961 to control the lodgepole needle miner had relatively little effect on the balance between the miner and native parasitic insects.

1520. Struble, George R.
1969. *Lodgepole needle miner controlled by aerial sprays.* Proc. 6th World For. Congr., Madrid, Spain, 1966(2):1946-1950.
Describes a long-term investigation that led to a successful method of direct control.

1521. Swain, Kenneth M., and Boyd E. Wickman.
1967. *Lindane can help control California flatheaded borer in Jeffrey pine.* U.S. Forest Serv. Res. Note PSW-162, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A 1.5 percent formulation of lindane in diesel oil proved to be an effective insecticide against all stages of the insect.

1522. Tiernan, C. F., and R. P. Miskus.
1971. *Toxicity of Zectran to spruce budworm as a function of application site.* J. Econ. Entomol. 64(5):1307-1308, illus.
Mortality was greatest when application was made to the head and steadily declined rearward to the sixth abdominal segment.

1523. U.S. Forest Service.
1965. *Evaluation of chemicals for control of forest insects—a research and development project at the Pacific Southwest Forest and Range Experiment Station.* 8 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes aims of a new research and development team organized to find and test safer, more specific, and less persistent chemicals, and improved methods of application for use against destructive forest insects.

1524. Walters, Gerald A.
1972. *Pesticide treatments on saligna eucalyptus, Australian toon seedlings affect dieback but not survival.* Tree Planters' Notes 23(3):16-18.
The pesticides did not affect survival, but did affect the number of seedlings which died back, and thus affected early growth.

1525. Walton, Gerald S.
1968. *Log-normal spray drop distribution . . . analyzed by two new computer programs.* USDA Forest Serv. Res. Note PSW-174, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes two Fortran IV computer programs written for analyzing size distribution properties of drops from spray nozzles.

1526. Wickman, Boyd E., and Robert L. Lyon.
1962. *Experimental control of the mountain pine beetle in lodgepole pine with lindane.* J. For. 60(6):395-399, illus.
Describes a successful field trial and discusses the evaluation of such a test.

1527. Williams, Carroll B., Jr., and Gerald S. Walton.
1968. *Effects of Naled and Zectran on spruce budworm and associated insects in Montana.* J. Econ. Entomol. 61(3):784-787.
Zectran was uniformly effective against all budworm larval stages, whereas Naled was not as toxic to 6th-instar larvae as with previous instars.

1528. Williams, Carroll B., Jr., Gerald S. Walton, and C. F. Tiernan.
1969. *Zectran and Naled affect incidence of parasitism of the budworm Choristoneura occidentalis in Montana.* J. Econ. Entomol. 62(2):310-312.
Parasitization by *Apanteles* greatly increased, and that by *Glypta* and tachnids declined after spraying with Zectran whereas parasitization by both *Apanteles* and *Glypta* declined after spraying with Naled.

1529. Williams, Carroll B., Jr., and Patrick J. Shea.
1971. *Insecticides.* In *Toward integrated control,* p. 88-110. USDA Forest Serv. Res. Paper NE-194, Northeastern Forest Exp. Stn., Upper Darby, Pa.
Highlights the recent history of the use of insecticides in combating forest pests, including work on finding a replacement for DDT.

1530. Williams, Carroll B., Jr.
1973. *Field tests of four insecticides against the Douglas-fir tussock moth in Oregon.* Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc., Portland, Oreg. 1973:77-83.
Treatments with Zectran, carbaryl, dylox, or bioethanomethrin reduced insect populations and saved tree foliage when compared with no treatments, but the test results were highly variable and inconsistent.

FOREST FIRE

Fire Management

1531. Abell, C. A.
1940. *Fires on the National Forests of southern California with respect to final area and distance traveled by the suppression crew on foot.* 9 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Tabulates fires to show the degree to which fire occurrence is associated with roads.

1532. Bentley, Jay R., and Verdie E. White.
1961. *The fuel-break system for the San Dimas Experimental Forest.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 63, 9 p., illus. Berkeley, Calif.
Seventy-four miles of 200- to 400-foot fuel-breaks laid out after the wildfire will break future brushfields into small units which will help to keep fires small.

1533. Bjornsen, Robert L., and Richard A. Chase.
1971. *Computer simulates fire planning problem.* Fire Control Notes 32(4):12-13, illus.
A simulation model called FOCUS (Fire Plan Operation Characteristics Using Simulation) is being developed to predict probable consequences of available alternatives in fire planning.

1534. Bratten, Frederick W.
1970. *Advanced concepts for forest fire command and control systems.* News and Views (Florida Forest Serv.), January 1970:20-25.
Discusses the data-handling and decisionmaking capabilities of modern computers and communication systems and their possible application to the large fire problem.

1535. Bratten, Frederick W.
1970. *Allocation model for firefighting resources . . . a progress report.* USDA Forest Serv. Res. Note PSW-214, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a suppression planning problem and its solution, using a computer to perform the resource allocation and plan evaluation functions.

1536. Broido, A.
1964. *Some problems in fire research.* Pyrodynamics 1:27-40, illus.
Describes some of the problems associated with large-scale fires in an attempt to indicate the need for considerable additional research effort.

1537. Brown, A. A.
1935. *Improving forest fire detection in California.* J. For. 33(11):923-931.
Describes how the complex problem of selecting and distributing lookouts for maximum efficiency in fire control was solved.

1538. Brown, A. A.
1936. *Receding string reels for dispatcher maps.* Fire Control Notes 1:41-42.
A small, enclosed spool mounted on a shaft fastened to a coil spring wound with fishing line tied to a glass headed push pin can be used for plotting seen area on dispatcher maps.

1539. Brown, A. A., and F. W. Funke.
1936. *Redesigning plans of communication for the national forests of California.* J. For. 34(7):708-714.
Reports on preparations to improve telephone communications by replacing and/or repairing existing networks.

1540. Brown, A. A.
1936. *Road speed compass.* Fire Control Notes 1:29.
Bow compasses outfitted with an index pointer and accurate scale can be used to determine the distance that can be traveled within a given time limit.

1541. Brown, A. A.
1936. *Vertical angle finder.* Fire Control Notes 1:39-40.
A simple vertical angle reader was developed as a supplementary instrument to alidades.

1542. Brown, A. A.
1937. *Design of national forest transportation plans to meet the fire control problem in northern California.* J. For. 35(5):490-495.
Describes the principles and procedure developed to provide for acceptable speed of first attack and to facilitate effective fire-suppression strategy on going fires.

1543. Brown, A. A.
1937. *Design of national forest transportation plans to meet the fire control problem in southern California.* J. For. 35(6):563-570.
Describes forest service-developed transportation plan

for fire control efficiency.

1544. Brown, A. A.
1937. *Fire control progress in California national forests.* Timberman 38(6):18, 20, 22.
A series of planning projects gives assurance of quicker and better performance in areas of detection, report, get-away and travel.

1545. Brown, A. A.
1936. *Planning fire lookouts in California.* Am. Forests 42(5):214-215.
A careful study was made utilizing information on fire frequency and visible area in order to establish a statewide network of forest fire lookouts.

1546. Bruce, H. D.
1941. *Theoretical analysis of smoke-column visibility.* J. Agric. Res. 62(3):161-178.
Derives an equation for the maximum distance a given smoke can be seen based on contrast ratio expressed in terms of the light flux entering the observer's eye from the smoke, the haze, and the background.

1547. Bruce, H. D.
1944. *Observations on the visibility of a small smoke.* J. For. 42(6):426-434.
Since accuracy of smoke detection depends on the position of the sun, haziness, and background visibility, lookout personnel should be given a full understanding of the relationship of these variables and trained in their application.

1548. Buck, Charles C., and Wallace L. Fons.
1935. *The effect of direction of illumination upon the visibility of a smoke column.* J. Agric. Res. 51(10):907-918.
The increasing brightness of suspensoid particles with increasing angle between the sun and observer's line of sight makes it easier to detect smoke column at greater distances in the general direction of the sun than in the opposite direction.

1549. Buck, Charles C.
1938. *Factors influencing the discovery of forest fires by lookout observers.* J. Agric. Res. 56(4):259-266.
Three discovery-time factors—distance, rate of spread, and position of the sun—were measured and their interrelation with respect to discovery time determined.

1550. Buck, Charles C., and John E. Hughes.
1939. *The solvent distillation method for determining the moisture content of forest litter.* J. For. 37(8):645-651.
The xylene distillation method is a quick and accurate alternative to the oven drying method for determining moisture content.

1551. Buck, Charles C., H. D. Bruce, C. A. Abell, and W. L. Fons.
1941. *A forest fire protection problem analysis for California.* 143 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Analyzes 77 problems covering the fields of fire prevention, presuppression, suppression, and fire effects.

1552. Buck, Charles C., and C. A. Abell.
1942. *Recommendations of the California Forest and Range Experiment Station for emergency fire protection in the East Bay Hills area.* 10 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Recommends improved fire prevention, detection, and dispatching techniques to protect war industries in the area from saboteur-caused fires.

1553. Buck, Charles C., and C. A. Abell.
1951. *Inflammability of chaparral depends on how it grows.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper No. 2, 2 p. Berkeley, Calif. [Essentially the same article appeared in Fire Control Notes 12(4):27, under the title *Flammability of chapparal depends on how it grows.*]
Drought conditions in southern California prevented new growth from balancing large increases in dead branches and leaves on chaparral shrubs, thereby increasing the fire danger for the 1951 fire season.

1554. Burgan, Robert E., Francis M. Fujioka, and George H. Hirata.
1974. *A fire-danger rating system for Hawaii.* Fire Technol. 10(4):275-280.
The fine-fuel model of the National Fire Danger Rating System has been implemented, on an automated basis, to rate the forest fire danger in Hawaii.

1555. Carpenter, Stanley B., Jay R. Bentley, and Charles A. Graham.
1970. *Moisture contents of brushland fuels desiccated for burning.* USDA Forest Serv. Res. Note PSW-202, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Discusses effects of herbicides on moisture content of a manzanita brushfield that already had a continuous fuel bed of litter and small dead upright stems.

1556. Chandler, Craig C.
1957. *"Light burning" in southern California fuels.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 119, 2 p. Berkeley, Calif.

Fuel studies made during Operation Firestop in 1954 show that light burns accomplished little in the way of hazard reduction.

1557. Chandler, Craig C.
1960. *Developing a measure for various man-caused fire risks.* Fire Control Notes 21(2):31-34.
Discusses the role of statistics in fire prevention planning, and outlines steps to measure the relative risk of fire from various types of forest use.

1558. Chandler, Craig C.
1961. *Risk rating for fire prevention planning.* J. For. 59(2):93-96.
The process of measuring and compiling the four variables relating to the chance of a man-caused fire starting—weather, fuels, human use, and prevention effectiveness—is described and the computation of a risk number is illustrated.

1559. Countryman, Clive M.
1960. *Fire environment and silvicultural practice.* Soc. Am. For. Proc. 1959:22-23.
Silvicultural practice is one of the several factors that can affect fire environment and hence fire hazard.

1560. Countryman, Clive M.
1960. *Rating fire danger by the multiple basic index system.* J. For. 64(8):531-536, illus.
The multiple index concept identifies the component parts of total fire danger and the factors (fire danger determinants) that control them.

1561. Countryman, Clive M.
1969. *Fuel evaluation for fire control and fire use.* J. Ariz. Acad. of Sci. Proc. Symp. on Fire Ecol. and Control and Use of Fire in Wildland Manage. 1969:30-38, illus.
To promote efficient fire control and effective use of fire, the effect of man's impact on the fuels and fire potential of a wildland area must be evaluated.

1562. Countryman, Clive M.
1969. *Use of air tankers pays off—a case study.* USDA Forest Serv. Res. Note PSW-188, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Even though fire suppression costs in the 1967 Timber Canyon Fire increased by about $39,000 over what they would have been without air tankers, the fire damages were decreased by $501,375, giving a "profit" of $461,574.

1563. Countryman, Clive M.
1971. *Carbon monoxide—a firefighting hazard.* 6 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Concentrations of carbon monoxide high enough to have adverse effects on firefighters are likely to occur in many wildland fires.

1564. Countryman, Clive M.
1971. *This humidity business: What it is all about and its use in fire control.* 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Defines the meanings of different air moisture terms, and explains why relative humidity is so important in wildland fire control activities.

1565. Countryman, Clive M.
1974. *Can southern California wildland conflagrations be stopped.* USDA Forest Serv. Gen. Tech. Rep. PSW-7, 11 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Suggests that the best prospect for alleviating this fire problem is to create fuel situations that will reduce the energy output of such fires to a point where conventional firefighting methods will be effective.

1566. Court, Arnold.
1960. *Lightning fire incidence in northeastern California, 1945-1956.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 47, 21 p., illus. Berkeley, Calif.
Analyzes records which indicate that lightning causes more fires in northeastern California than in all the rest of the state combined, and reports timing, season, trend, and other details of lightning-fire incidence on public and private lands.

1567. Cuff, K. A., and R. N. Neuns.
1952. *Use of aerial photos on Boardman Ridge fire.* Fire Control Notes 13(2):33
Valuable fire control information was derived from existing files of aerial photos, enabling fire control officers to direct the activities of crews in smoke-obscured areas.

1568. Curry, John R.
1933. *Binocular telescopes in forest fire detection.* J. For. 31(1):51-58.
Suggests specifications for binoculars used in fire detection.

1569. Curry, John R.
1934. *Azimuth circle printer.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 5, 1 p. Berkeley, Calif.
Describes a device to print azimuth circles on maps used for fire dispatching from lookout towers.

1570. Curry, John R.
1934. *Gowen elapsed time slide rule; Gowen timekeeper's slide rule.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 4, 2 p. Berkeley, Calif.
Describes devices used to determine elapsed time of fires and to compute firefighter wages.

1571. Curry, John R.
1934. *Indexes of forest fire control; National Forests Region 5 - California, 1921-1933.* 25 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 4, 2 p. Berkeley, Calif.
Develops indexes to be used for the purpose of evaluating fire control unit efficiency.

1572. Curry, John R.
1936. *Use of mill scale binoculars in fire detection.* Fire Control Notes 1:37-38.
Recommends the use of mill scales on binoculars and provides a nomograph for determining fire diameters from a distance.

1573. Curry, John R.
1937. *The future of fire control.* Fire Control Notes 1(5):255-257.
Fire control development is handicapped by the old idea that the fire problem is one of temporary importance; a program is needed which provides for an understanding of the basic principles and the development of skills and techniques.

1574. Curry, John R.
1938. *The field of forest-fire protection.* Fire Control Notes 2(1):1-6.
Suggests the use of fire protection as an all inclusive term in an attempt to clarify definitions and interrelationships between prevention, presuppression, suppression, fire behavior, damage, and economic considerations.

1575. Curry, John R.
1938. *Forest fire danger rating in the California region.* U.S. Forest Serv. Rural Fire Inst. 4th Pomona, Calif., Proc. 1938:60-63.
Presents an analysis of the problem of rating and develops general principles of a theoretical fire danger rating system.

1576. Curry, John R., Leslie G. Gray, and I. Clare Funk.
1940. *Forest fire-danger rating and its application in California.* J. For. 38(11):855-866.
Relates the application of fire-danger ratings to fire control planning.

1577. Davis, James B., Dean L. Dibble, and Clinton B. Phillips.
1961. *Firefighting chemicals—new weapons for the fire suppression crew.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 57, 27 p., illus. Berkeley, Calif.
Field tests of viscous water, viscous diammonium phosphate, and bentonite foam by tanker crews on 40 forest fires indicate that viscous water can be a substantial help to a crew fighting a hot fire.

1578. Davis, James B., Dean L. Dibble, and Kenneth L. Singer.
1962. *Tests of fire retardant chemicals at Plum Creek.* 26 p., illus. Calif. Air Attack Coord. Comm. Rep. Calif. Div. Forestry, Sacramento, Calif.
Tests on small controlled fires in natural brush fuels showed that thickened solutions of diammonium phosphate and ammonium sulphate are probably superior to fire retardants now in use.

1579. Davis, James B., Dean L. Dibble, Clinton B. Phillips, and Robert S. McBride.
1962. *Viscous water and algin gel as fire control materials.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 71, 26 p., illus. Berkeley, Calif.
A study indicates that viscous water and algin gel are more effective than plain water for knocking down hot fires in most forest fuels.

1580. Davis, James B.
1963. *Dropping fire retardants by helicopter—tests of three new helitanks.* U.S. Forest Serv. Res. Note PSW-27, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Late model helicopters equipped with new helitanks delivered accurately as much fire retardant as most fixed-wing air tankers at potentially lower cost.

1581. Davis, James B., Clinton B. Phillips, Dean L. Dibble, and Leo V. Steck.
1963. *Operational tests of two viscous DAP fire retardants.* U.S. Forest Serv. Res. Note PSW-14, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Operational tests confirmed earlier laboratory and field studies and showed that viscous solutions of diammonium phosphate are more effective than other known fire retardants.

1582. Davis, James B., and Clinton B. Phillips.
1965. *Corrosion of air tankers by fire retardants.* 38 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Serious corrosion damage was found on the tank and

gates of one air tanker in an examination of 26 air tankers and four non-air tankers.

1583. Davis, James B., Dean L. Dibble, S. S. Richards, and Leo V. Steck.
1965. *Gelgard—a new fire retardant for air and ground attack.* Fire Technol. 1(3):216-224, illus.
Describes the properties of Gelgard, reports the results of laboratory and field tests, and compares its effectiveness to that of plain water and other viscosity agents.

1584. Davis, James B., and Marvin Dodge.
1968. *Do fire retardants contaminate helicopters?* Fire Technol. 4(1):17-24, illus.
Micro-residue techniques used to determine the quantity of fluorescent dye reaching small mylar tape pieces located on the helicopter showed that little or no retardant reached the helicopter.

1585. Davis, James B.
1968. *Forest fire control decision making under conditions of uncertainty.* J. For. 66(8):626-631.
Discusses game theory and decision theory for possible use in forest fire control decisionmaking and describes several types of matrix games, subjective utility, and various criteria for strategy selection.

1586. Davis, James B.
1970. *Systems analysis and the rural fire department: problems in design.* Fire J. 64(2):84-87.
Points out some of the problem areas in applying systems analysis to rural fire protection and suggests some solutions.

1587. Davis, James B.
1971. *Diammonium phosphate prevents roadside fires.* Fire Control Notes 32(1):7-9, illus.
Diammonium phosphate, a retardant similar to that used in air tankers, significantly reduced the number of roadside fires during a 5-year test on the Angeles National Forest, California.

1588. Deeming, James E., James W. Lancaster, Michael A. Fosberg, and others.
1972. *National fire-danger rating system.* USDA Forest Serv. Res. Paper RM-84, 165 p., illus. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo.
Based on the physics of fire behavior, the National Fire-Danger Rating System produces three indexes—Occurrence, Burning, and Fire Load—that measure relative fire potentials.

1589. Dell, John D.
1965. *A new fire experimental area in southern California.* Fire Control Notes 26(3):5-7, illus.
An area including 13,000 acres of chaparral will be used as a field laboratory for cooperative forest fire studies, field tests of new equipment, and demonstration and training.

1590. Dell, John D., and Charles W. Philpot.
1965. *Variations in the moisture content of several fuel size components of live and dead chamise.* U.S. Forest Serv. Res. Note PSW-83, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Finds that leaves were the only fuel components of live chamise with appreciable seasonal moisture fluctuation and that dead chamise showed little or no variation due to fuel size or season of the year.

1591. Dell, John D.
1967. *Fuel treatment.* Proc. Northwest Forest Fire Council Annu. Meet. 1967:55-61.
Suggests ways that flammable fuels might be removed or reduced to protect special areas from fire.

1592. Dell, John D., and Franklin R. Ward.
1970. *Building firelines with liquid explosive . . . some preliminary results.* USDA Forest Serv. Res. Note PSW-200, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Liquid explosives were effective in brush, understory vegetation, and light-medium slash, but not in deep, heavy slash.

1593. Dell, John D., and George I. Schram.
1970. *Oscillating sprinklers backup for burnout.* Fire Control Notes 31(2):8-10, illus.
Describes the effective use of a sprinkler water distribution system (originally designed for use on slash burns) for fireline reinforcement during a burnout operation.

1594. Dell, John D.
1970. *Road construction slash—potential fuse for wildfire.* Fire Control Notes 31(1):3, illus.
To reduce fire hazard and improve appearance of the forest, a complete clearing of roadside debris is suggested.

1595. Dell, John D., and Don E. Franks.
1970. *Thinning slash contributes to two eastside Cascade wildfires in Oregon.* Fire Control Notes 32(1):4-6, illus.
Analyzes two early-season wildfire occurrences in slash created from precommercial thinning of ponderosa pine, and points out the factors that contributed to fire ignition and spread.

1596. Dibble, Dean L., S. S. Richards, and Leo V. Steck.
1961. *Testing and evaluating chemical fire retardants in the laboratory.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 59, 11 p., illus. Berkeley, Calif.
This is the first step in a study program that includes laboratory, field, and operational testing before a new material is accepted for practical application.

1597. Dibble, Dean L., S. S. Richards, and Leo V. Steck.
1962. *Testing and evaluating chemical fire retardants in the laboratory.* Fire Control Notes 23(1):18-22.
Describes procedures used to screen proposed chemical fire retardant, the first step in a study program that includes laboratory, field, and operational testing.

1598. Dibble, Dean L.
1963. *Roadside hazard reduction with fire retardant chemicals.* U.S. Forest Serv. Res. Note PSW-21, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The use of fire retardant chemicals for season-long fireproofing of roadside vegetation is promising, but solubility of the retardant residue, concentration, and application techniques need further study.

1599. Dibble, Dean L., and James B. Davis.
1967. *Fighting fire with high pressure air jets . . . some preliminary results.* Fire Control Notes 28(1):12-13, 15, illus.
Compressed air as a means of propelling retardant liquids or powder appears promising.

1600. Dodge, Marvin.
1966. *Mass helitack on large fires in California.* Fire Control Notes 27(4):4-5, illus.
In the first mass attack by helicopter, operations included transport of men and material and retardant drops in close support of ground crews.

1601. Dodge, Marvin.
1969. *Tracer shotshell fires, a new hazard.* Fire Control Notes 30(1):5, illus.
In laboratory tests, tracers shot into flammable materials started fires whereas tracers shot into the air burnt out before they hit the ground.

1602. Dodge, Marvin.
1970. *Nitrate poisoning, fire retardants, and fertilizers—any connection?* J. Range Manage. 23(4):244-247, illus.
The possibility of injury to livestock from chemical fire retardants appears to be slight—much less than from range or pasture fertilization.

1603. Dunning, Duncan.
1929. *Fire in the foothills, the problem of controlling fires in the marginal brush lands of California.* Calif. Countryman 15(7):6, 16-17.
Discusses the responsibility for developing a carefully coordinated program of fire protection which considers the value of the land, weather, and the effects of devastation.

1604. Edmunson, George C., Jr., and Donald R. Cornelius.
1961. *Promising grasses for southern California fuel-breaks.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 58, 13 p. Berkeley, Calif.
Recommends grass species for 7 climatic zones and reports results of test plantings with 13 perennial and 3 annual grasses.

1605. Edmunson, George C., Jr., and Donald R. Cornelius.
1961. *Ryegrasses for southern California fuel-breaks.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 186, 6 p., illus. Berkeley, Calif.
Reports from a 2-year trial including 12 strains of ryegrass recommend Wimmera ryegrass over commercial ryegrass for fuel-break and chaparral watershed seeding.

1606. Edmunson, George C., Jr., Lisle R. Green, and Jay R. Bentley.
1961. *Seed distribution in the swath from helicopter sowing.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 190, 8 p., illus. Berkeley, Calif.
Seeds of all species were fairly well distributed over a 40-foot swath, with adequate overlap of swaths.

1607. El-Agizy, M.
1963. *Fire detection model with multiple lookout optimizing the allocation of search time.* Res. Rep. ORC 63-10, 30 p. Univ. Calif. Oper. Res. Center, Berkeley, Calif.
Proposes a mathematical model for optimizing the allocation of search time in fire detection.

1608. Ely, J. B., and A. W. Jensen.
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1609. Ely, J. B., A. W. Jensen, L. R. Chatten, and H. W. Jori.
1957. *Air tankers—a new tool for forest fire fighting.*

Fire Control Notes 18(3):103-109.
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1610. Fenner, Ralph L.
1953. *A safe, cheap, and effective forest fire grenade.* Fire Control Notes 14(2):22-24.
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1611. Fons, W. L., and C. M. Countryman.
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Studies of effects of eight litter types on readings of fuel moisture stick indicators.

1612. Fons, W. L.
1950. *Wet water for forest fire suppression.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 71, 5 p. Berkeley, Calif.
Describes tests of wetting agents used in fire control activities.

1613. Fons, W. L., and R. S. McBride.
1950. *Wet water for pretreating litter fuels.* Fire Control Notes 11(2):26-27.
During construction of firelines, wetting agents applied to litter in adjacent areas provide safety margin for firefighters.

1614. Fosberg, Michael A., James W. Lancaster, and Mark J. Schroeder.
1970. *Fuel moisture response—drying relationships under standard and field conditions.* Forest Sci. 16(1):121-128, illus.
This relationship may be used to compare the moisture change of a specific fuel during a specified time or the time required to reach a specified moisture content under field conditions, to the moisture change or time under standard conditions.

1615. Fosberg, Michael A., and Mark J. Schroeder.
1971. *Fine herbaceous fuels in fire danger-rating.* USDA Forest Serv. Res. Note RM-185, 7 p., illus. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo.
Describes a procedure for determining the effects of fuels on rate of fire spread through solutions of simultaneous sets of equations for rate-of-spread, with various proportions of living herbaceous vegetation.

1616. Fuel-break Executive Committee.
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Describes how the Glendora Ridge Fuel-Break aided fire control crews in containing a fire under adverse wind conditions.

1617. Fuel-break Executive Committee.
1962. *Interim guidelines for fuel-breaks in southern California.* Fuel-Break Rep. No. 7, 15 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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1618. Furman, R. William, and Robert S. Helfman.
1973. *Computer time-sharing used with NFDRS.* Fire Manage. 34(2):14-16, illus.
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1619. Gordon, Donald T.
1962. *A prototype fuel-break in the eastside ponderosa-Jeffrey pine type.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 207, 9 p., illus. Berkeley, Calif.
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1620. Gordon, Donald T.
1967. *Alternatives in fire-management strategies.* Conf. on Young-Growth Forest Manage. Proc. 1967:115-119.
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1621. Gordon, Donald T.
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Three prescribed burns are described in terms of meteorological factors, fire behavior, and burning effect.

1622. Gowen, George M., J. R. Curry, and A. A. Brown.
1936. *Visible-area mapping of lookout points, methods and technique.* 15 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.

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1623. Green, Lisle R.
1963. *The fuel-break program.* 15th Annu. Calif. Weed Conf. Proc. 1963:109-112.
Gives a history of the fuel-break program and a detailed description of methods used in chemical control of brush and research on grass establishment on fuel-breaks.

1624. Green, Lisle R., G. C. Edmunson, D. R. Cornelius, and A. B. Evanko.
1963. *Seeding fuel-break areas in southern California.* Fuel-Break Rep. 10, 18 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Recommendations based on research and field experience include grass species and rates, planting methods and sites, seedbed preparation, date to seed, and seeding costs.

1625. Green, Lisle R.
1965. *The search for a 'fire resistant' plant in southern California.* Calif. Div. For. Fire Control Exp. 10, 12 p., illus.
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1626. Green, Lisle R., and Jay R. Bentley.
1967. *Fuel-breaks for forest fire control.* Span 10(2):6 p., illus.
Describes how a variation of the fire-break—known as the fuel-break—has been developed in California and how the technique makes use of herbicides and modern, heavy machines.

1627. Green, Lisle R.
1967. *The search for slow burning vegetation.* Proc. Northwest Forest Fire Counc. Annu. Meet. 1967:39-49.
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1628. Green, Lisle R.
1970. *An experimental prescribed burn to reduce fuel hazard in chaparral.* USDA Forest Serv. Res. Note PSW-216, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports a test of burning under prescribed fuel and weather conditions when untreated brush would not burn readily.

1629. Green, Lisle R., and Harry E. Schimke.
1971. *Guides for fuel-breaks in the Sierra Nevada mixed conifer type.* 14 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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1630. Green, Lisle R., and Gene W. Benedict.
1971. *Herbicides to prevent forest fires.* Proc. Wash. State Weed Conf., Yakima, Wash. 1971:73-79.
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1631. Green, Lisle R.
1972. *The fuel-break concept in wildland fire control.* Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc. 1972:28-32.
Summarizes work on developing the fuel-break concept, construction of fuel-breaks, controlling woody regrowth and revegetation, and evaluates the performance of fuel-breaks in wildfires.

1632. Greulich, Francis E., and William G. O'Regan.
1975. *Allocation model for air tanker initial attack in firefighting.* USDA Forest Serv. Res. Note PSW-301, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a model for allocating air tanker operations on forest fires.

1633. Hanson, P. D., and C. A. Abell.
1941. *Determining the desirable size of suppression crews for the National Forests of northern California.* Fire Control Notes 5(3):156-160.
Estimates are made according to precedents set by the rates of spread of past fires and the number of men who controlled them.

1634. Hardy, E. C., R. C. Rothermel, and J. B. Davis.
1962. *Evaluation of forest fire retardants—a test of chemicals on laboratory fires.* U.S. Forest Serv. Intermountain Forest and Range Exp. Stn. Res. Paper 64, 33 p., illus. Fort Collins, Colo.
A test of seven retardants to reduce fire spread and radiant and convective heat output showed that three materials—pectin-DAP, algin-DAP, and Fire-Trol—appeared to be the most effective retardants.

1635. Heyman, Daniel P.
1964. *Least cost location of fire suppression equipment.*

Res. Rep. ORC-64-4, 22 p. Univ. Calif. Oper. Res. Center, Berkeley, Calif.
Gives an analysis of the best locations for optimally sized crews along a certain length of a road where the probability of ignitions as well as the distributions of damage cost, initial fire spread rates, and rates of travel are known.

1636. Irwin, Robert L., and Donald C. Halsey.
1974. *Two-agency group completes planning in record time.* Fire Manage. 35(2):16-17, 22.
In less than 30 days, the U.S. Bureau of Land Management and U.S. Forest Service were able to complete jointly a fire plan covering all phases of fire management for a 100,000-acre area in Arizona.

1637. Jensen, A. W., and M. J. Schroeder.
1958. *A new measure of the build-up for fire danger rating in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 133, 5 p., illus. Berkeley, Calif.
Describes the procedure used to determine the effect of the drying of heavy fuels on fire danger and to integrate this build-up factor into the California fire-danger rating system.

1638. Jewell, William S.
1962. *Forest fire problems—a progress report.* Res. Rep. F-2, IER 172-36, 19 p. Univ. Calif. Oper. Res. Center, Berkeley, Calif.
Reports progress of operations research studies of initial attack planning, man and equipment mobilization, economics of detection systems, fire camp organization, and fire agency communications.

1639. Jewell, William S., and Gaylord K. Parks.
1962. *A preliminary model for initial attack.* Summary Rep. F-1, IER 172-31, 41 p. Univ. Calif. Oper. Res. Center, Berkeley, Calif.
This simple model indicates the size of suppression forces that will be most economical for fires of various sizes and growth potentials.

1640. Jewell, William S.
1963. *Forest fire problems—a progress report.* J. Oper. Res. Soc. Am. 11(5):678-692, illus.
Discusses studies of problem areas—initial attack, mobilization of suppression forces, detection systems, fire camp organization, and fire agency communication—and states limitations to the studies.

1641. Jewell, William S.
1965. *Forest fire-fighting models.* Univ. Calif. Oper. Res. Center ORC 65-29, 20 p. Berkeley, Calif.
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1642. Johnston, Ralph, Cal Ferris, and James Davis.
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1643. Kotok, E. I.
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1644. Kotok, E. I.
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1645. Kotok, E. I.
1929. *Relative risk and hazard* West Coast Lumberman 56(4):25-26.
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1646. Kotok, E. I.
1930. *Fire, a problem in American forestry.* Sci. Monthly 31:450-452.
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1647. Kotok, E. I., Evan W. Kelley, and C. F. Evans.
1933. *Protection against fire.* In *A national plan for American forestry,* p. 1395-1414. U.S. Forest Serv., Washington, D.C.
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1648. Kourtz, Peter H., and William G. O'Reagan.
1968. *A cost-effectiveness analysis of simulated forest fire detection systems.* Hilgardia 39(12):341-365, illus.
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1649. Kourtz, Peter H., and William G. O'Reagan.
1971. *A model for a small forest fire . . . to simulate burned and burning areas.* Forest Sci. 17(2):163-169, illus.
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1650. Kurth, Troy.
1968. *The combination helitanker-air tanker attack on the Pine Creek Fire.* Fire Control Notes 29(4):3-5, illus.
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1651. Lindquist, James.
1970. *Building firelines—How fast do crews work?* Fire Technol. 6(2):126-134, illus.
Rates of producing firelines by crews were evaluated from data from actual fires in California, with productivity rates given in both square yards and chains per man hour.

1652. Maxwell, Floyd D.
1971. *A portable IR-system for observing fire thru smoke.* Fire Technol. 7(4):321-331, illus.
A near-infrared system developed to improve the human capability to observe fire in the presence of smoke can also image background or surrounding area to provide perspective.

1653. Maxwell, Floyd D.
1973. *Do carbon particles start fires?* Perm. Assoc. Comm. Proc., West. For. and Conserv. Assoc., Portland, Oreg. 1973:40-42.
Engine exhaust particles do start fires, and the chief active constituent of the particles is the crankcase lubricant.

1654. McBride, Robert S.
1950. *Corrosion of metals by wet water.* Fire Control Notes 11(2):31-32.
Reports that potassium dichromate can reduce corrosion in fire fighting equipment caused by wetting agents.

1655. McMasters, A. W.
1963. *Preliminary analysis of the influence of hand crews on fire growth.* Res. Rep. ORC 63-7, 34 p. Univ. Calif. Oper. Res. Center, Berkeley, Calif.
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1656. Mees, Romain M.
1973. *Forest fire history . . . a computer method of data analysis.* USDA Forest Serv. Gen. Tech. Rep. PSW-4, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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1657. Mees, Romain M.
1974. *An algorithm to help design fire simulation and other data base work.* USDA Forest Serv. Gen. Tech. Rep. PSW-9, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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1658. Mees, Romain M.
1974. *Computer graphs fire reports in three-dimensional form.* Fire Manage. 35(1):17, illus.
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1659. Miller, Harry R.
1956. *Chemical fire retardants for wild land fire control.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 105, 5 p. Berkeley, Calif.
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1660. Miller, Harry R., and Carl C. Wilson.
1957. *A chemical fire retardant—results of field trials using sodium calcium borate on forest fires in 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 15, 20 p., illus. Berkeley, Calif.
Shows sodium calcium borate to be a useful tool, and emphasizes the need for equipment to simplify and speed up the mixing of chemicals for ground and air tankers and for use guidelines.

1661. Miller, Harry R., and H. P. Reinecker.
1958. *Air tanker report—California, 1957.* Fire Control Notes 19(2):53-56, illus.
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1662. Miller, Harry R., and Clinton B. Phillips.
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fire retardants, notes the study yet required on these materials, and lists the characteristics of an ideal fire retardant.

1663. Morley, James P.
1966. *Physiological factors affecting night helicopter flight.* Fire Control Notes 27(4):6-7, illus.
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1664. Murphy, Eugene E., and James L. Murphy.
1965. *Value of a timber fuel-break—the Wet Meadow Fire.* Fire Control Notes 26(4):3-4, illus.
A fuel-break on the Stanislaus National Forest was credited with enabling firefighters to stop a potentially large fire at 23 acres.

1665. Murphy, James L.
1957. *Helicopter message or cargo drop-and-pickup kit.* Fire Control Notes 18(4):152-155, illus.
Shows how a drop-and-pickup unit for helicopters can solve communication problems arising when use of radio is limited, if crew has been properly instructed in safety practices.

1666. Murphy, James L.
1958. *Ground operations for helicopters.* Fire Control Notes 19(2):74-78, illus.
Describes helicopter ground crew organization and duties as well as how to locate, construct, and operate heliports and helispots safely and efficiently.

1667. Murphy, James L.
1958. *Helitack crews pay off in California.* Fire Control Notes 19(2):94-96.
Describes use of specially trained helitack crews in California in 1957 to suppress small remote forest fires in their early stages and to aid on large fires.

1668. Murphy, James L.
1958. *Training the helitack crew.* Fire Control Notes 19(2):91-93, illus.
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1669. Murphy, James L.
1959. *The helijump—the research and development of the helicopter hover-jump technique.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 32, 22 p., illus. Berkeley, Calif.
Reports tests leading to hover-jump technique, recommendations for helijump protective suit, and describes 4-pass jumping operation.

1670. Murphy, James L.
1959. *Helispot location and construction.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 31, 18 p., illus. Berkeley, Calif.
Describes practical methods of helispot location and construction in mountain topography.

1671. Murphy, James L.
1959. *Safety rules for helitack.* 7 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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1672. Murphy, James L.
1960. *Changes in the helitack training plan.* Fire Control Notes 20(3):77-79, illus.
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1673. Murphy, James L.
1960. *The helicopter and the dead man's curve.* Fire Control Notes 20(1):1-2, illus.
Emphasizes the importance of recognizing the take-off and landing limitations of helicopters, particularly in heavy timber.

1674. Murphy, James L.
1964. *Conflagration barriers—a new concept.* 54th West. For. Conf. Proc. 1963:10-12.
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1675. Murphy, James L., and Charles W. Philpot.
1965. *Do petroleum-based protective coatings add fuel value to slash?* U.S. Forest Serv. Res. Note PSW-81, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Results from fuel value determinations indicate that asphalt and wax slash coatings add very little to the fuel value of slash.

1676. Murphy, James L., and Harry E. Schimke.
1965. *Do wire fences stop ground fires?* U.S. Forest Serv. Res. Note PSW-70, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Wire fences of 1/8- to 1-inch mesh were not effective in

stopping fires in four fuel types on high fire danger days.

1677. Murphy, James L.
1965. *New developments in fire control systems.* Proc. West. For. and Conserv. Assoc. Annu. Meet. 1965:14-17, illus.
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1678. Murphy, James L., Harry E. Schimke, and Morris J. Garber.
1965. *Timber fuel-breaks and fuel moisture.* U.S. Forest Serv. Res. Note PSW-95, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports measurements of standard fuel moisture sticks in timber fuel-breaks with 20, 40, 60, and 80 percent crown closure.

1679. Murphy, James L.
1966. *Fuel weight and removal costs in fuel-break construction.* U.S. Forest Serv. Res. Note PSW-117, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Fuel weight per acre ranged from 13.2 to 420.6 tons per acre on the average with removal amounting to 27.9 percent to 40.5 percent of the total fuel.

1680. Murphy, James L., Lisle R. Green, and Jay R. Bentley.
1967. *Fuel-breaks—effective aids, not cure-alls.* Fire Control Notes 28(1):4-5, illus.
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1681. Murray, John R., and Charles W. Philpot.
1963. *The fuel temperature counter.* U.S. Forest Serv. Res. Note PSW-10, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Powered by a 24-volt wet cell battery, this device, containing temperature sensors, pulse generator, and counter-timer, will measure and record fuel temperature up to 2 weeks without attendance.

1682. Neuns, Alva G.
1950. *Chemicals for fire prevention.* Fire Control Notes 11(1):9-11.
Gives instructions for use of sodium chlorate, polybor chlorate, arsenic trioxide, razorite concentrate anhydrous and barascu for removal of grasses and weeds.

1683. Neuns, Alva G.
1950. *Water vs. fire. Fighting forest fires with water.* 38 p. Forest Serv. Calif. Reg. San Francisco, Calif.
Contains a training manual for firefighters.

1684. Nickey, Bradley B.
1975. *RAMP, a computer system for mapping regional areas.* USDA Forest Serv. Gen. Tech. Rep. PSW-12, 9 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
This computer-based system can convert locations expressed in section-township-range notation into latitude-longitude coordinates.

1685. Noste, Nonan V., and James B. Davis.
1975. *A critical look at fire damage appraisal.* J. For. 73(11):715-719, illus.
Discussion of fire-damage appraisal in relation to fire protection planning shows a need for a standard appraisal system on all Federal lands.

1686. O'Regan, William G., and Peter Kourtz.
1971. *A managerial decision system for an airborne infrared fire detection system.* Proc. Region Six Conf., Inst. Elect. and Electron. Eng., Sacramento, Calif. 1971(6B-1):1-5.
Describes the design, construction, and use of a simulator to provide efficient operating rules for an airborne infrared fire detection device.

1687. O'Regan, William G., Peter H. Kourtz, and Shirley Nozaki.
1975. *Patrol route planning for an airborne infrared forest fire detection system.* Forest Sci. 21(4):382-389.
Applies a linear program and a dynamic programing algorithm to solve the problem of spacing parallel flight lines within a specified patrol zone.

1688. Olsen, James M.
1959. *Setting up a green fuel moisture study.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 40, 4 p., illus. Berkeley, Calif.
Outlines establishment and methods in a study of the moisture content of green chaparral fuel.

1689. Olsen, James M.
1960. *Cistus, fuel moisture, and flammability.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 159, 2 p., illus. Berkeley, Calif.
A study of foliage moisture variations in cistus plantations on the San Bernardino National Forest showed no appreciable difference compared with a native brush species.

1690. Olsen, James M.
1960. *1959 green fuel moisture and soil moisture trends in southern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 161, 8 p., illus. Berkeley, Calif.
Correlates foliage moisture changes with soil moisture changes at depths dependent on the rooting habit of the particular brush species.

1691. Palmer, Thomas Y., and George D. Pace.
1974. *Microwave ovens for drying wildland fuels.* J. Microwave Power 9(4):289-293, illus.
Drying fuel in a microwave oven offers an economical, rapid method for determining fuel moisture content.

1692. Parks, George M.
1963. *Analytical models for attack and control of wildland fires.* Res. Rep. ORC 63-6, 188 p. Univ Calif. Oper. Res. Center, Berkeley, Calif.
Develops three analytical models to describe basic firefighting tactics—direct, indirect, and parallel—and suggests two stochastic models for determining optimal strategies in certain fire situations.

1693. Parks, George M.
1964. *Development and application of a model for suppression of forest fires.* Manage. Sci. 10(1):760-766, illus.
Summarizes formulation of the initial attack model, and applies the model results to fire control activities in a National Forest in California to determine the possible savings in total cost of the fire and acreage burned.

1694. Phillips, Clinton B., and Harry R. Miller, Jr.
1959. *Swelling bentonite clay—a new forest fire retardant.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 37, 30 p., illus. Berkeley, Calif.
Summarizes the results of laboratory and field tests.

1695. Phillips, Clinton B., and Harry R. Miller, Jr.
1959. *Using swelling bentonite clay as a fire retardant.* 11 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes some characteristics and suggests how to store dry bentonite powder and how to mix, store, and transfer bentonite slurry.

1696. Phillips, Clinton B.
1960. *Fighting forest fires from the air.* Soc. Am. For. Proc. 1959:137-140, illus.
Describes the rapid expansion in the use of air tankers, retardants, and helicopters for forest firefighting since 1954, and emphasizes that air attack is primarily a tactical support operation.

1697. Phillips, Clinton B., and Harry R. Miller, Jr.
1960. *A new forest fire retardant—swelling bentonite clay.* J. For. 58(12):948-951, illus.
Summarizes results of laboratory and field tests, and describes some of the characteristics which make it effective.

1698. Phillips, Clinton B., Louis E. Gunter, Grant E. McClellan, and Eamor C. Nord.
1972. *Creeping sage—a slow burning plant useful for fire hazard reduction.* Calif. Fire Control Notes 26, 8 p., illus.
Creeping sage is an ideal plant for reducing fire hazard because of its low stature, low fuel volume, and low rate of fire spread.

1699. Philpot, Charles W.
1963. *The moisture content of ponderosa pine and whiteleaf manzanita foliage in the central Sierra.* U.S. Forest Serv. Res. Note PSW-39, 7 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Studies showed that pine and manzanita had dissimilar moisture trends, the moisture content of brush varied with elevation during the growing season, and soil moisture was correlated with brush foliage moisture.

1700. Pirsko, Arthur R.
1958. *Red, white, or blue—wear an extra shirt on the fireline.* Fire Control Notes 19(3):102.
More than 99 percent of the heat from burning forest fuels is in the invisible infrared region of the spectrum, therefore the color of fire-fighters clothing is less important than protection by two layers of clothes.

1701. Pirsko, Arthur R., and Leo V. Steck.
1961. *A laboratory evaluation of liquid nitrogen and solid carbon dioxide as forest fire suppressants.* Fire Control Notes 22(4):120-122, illus.
Neither liquid nitrogen nor solid carbon dioxide proved to be effective in extinguishing deep-seated fires.

1702. Pirsko, Arthur R.
1961. *Selecting fire control planning levels by burning index frequencies.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 55, 7 p., illus. Berkeley, Calif. Also, Fire Control Notes 22(4):109-112, illus.
Reports that level of protection is most logically tied to a preselected probability level of fire weather conditions described by a burning index.

1703. Pirsko, Arthur R.
1961. *Why tie fire control planning to burning index?* Fire Control Notes 22(1):16-19, illus.

Reports how the burning index indicates the relative rate of spread and intensity of fires and describes the potential job load associated with fire suppression.

1704. Robinson, Lewis H.
1960. *An evaluation of three seasons of anti-lightning operations in California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 169, 8 p. Berkeley, Calif.
Summarizes the main points of an evaluation of cloud seeding operations with ground generators and suggests that plans for a routine operational program for seeding from the ground be discontinued.

1705. Rogers, D. H.
1942. *Measuring the efficiency of fire control in California chaparral.* J. For. 40(9):697-703.
Discusses the relation between fire history and possible size of fire in chaparral and offers a method of using this information to appraise the fire-control job and protection accomplishments.

1706. Sampson, Arthur W., and E. I. Kotok.
1929. *Burning vs. exclusion of fires on grass, chaparral, and forest lands.* 5 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes the main points presented at a forestry seminar on the subject of burning, including concise definitions of vegetative types, definitions of different intensities and kinds of burning operations, and the possible uses of different burning methods.

1707. Schimke, Harry E.
1963. *Tests of a wind machine as an aid to burning slash.* U.S. Forest Serv. Res. Note PSW-37, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The time and manpower used in handling the machine and its cost made it an impractical substitute for conventional slash disposal methods.

1708. Schimke, Harry E., and Ronald Dougherty.
1966. *A petroleum gel as a slash ignition aid and fuel booster.* U.S. Forest Serv. Res. Note PSW-97, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A petroleum gel in blivet and in bulk form promoted better ignition and burning of slash than did fuses and diesel oil under the same conditions.

1709. Schimke, Harry E., and James L. Murphy.
1966. *Protective coatings of asphalt and wax emulsions for better slash burning.* Fire Control Notes 27(3):5-6, 15.
Reports that coated slash piles burned better than uncoated piles.

1710. Schimke, Harry E., John D. Dell, and Franklin R. Ward.
1969. *Electrical ignition for prescribed burning.* 14 p., illus. USDA Forest Serv., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
On burns where area ignition is required, electrical circuitry can provide an effective means of ignition.

1711. Schimke, Harry E., and Lisle R. Green.
1970. *Prescribed fire for maintaining fuel-breaks in the central Sierra Nevada.* 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Explains methods and techniques, and suggests broad guidelines for use in comparable prescribed burning operations.

1712. Scowcroft, Paul G., James L. Murphy, and Lynn R. Biddison.
1967. *Importance of coordinated air-ground attacks. A comparison of two fires.* Fire Control Notes 28(2):6-7, illus.
Suggests that better equipped crews combined with greater use of improved air support and better coordination were primarily responsible for controlling a potentially dangerous fire with less damage than a similar fire earlier.

1713. Shephard, Ronald W., and W. S. Jewell.
1962. *Operations research in forest fire problems.* Summ. Rep. F-1, IER 172-19, 29 p. Univ. Calif. Oper. Res. Center, Berkeley, Calif.
Surveys the major forest fire problems, outlines possible operations research studies, and discusses obstacles to such studies.

1714. Show, S. B., and E. I. Kotok.
1923. *Forest fires in California, 1911-1920, an analytical study.* U.S. Dep. Agric. Dep. Circ. No. 243, 80 p. Gov. Print. Off., Washington, D.C.
Examines various protection theories, analyzes fire variations and the effects of these variations on control means, traces seasonal fluctuations in the fire intensity due to climactic changes, and points out certain weaknesses traceable to organizational flaws.

1715. Show, S. B., and E. I. Kotok.
1923. *The occurrence of lightning storms in relation to forest fires in California.* Monthly Weather Rev. 51(4):175-180.
Gives characteristics and the seasonal distribution of fires caused by lightning.

1716. Show, S. B., and E. I. Kotok.
1924. *The role of fire in the California pine forests.* U.S. Dep. Agric. Dep. Bull. 1294, 80 p. U.S. Gov. Print. Off., Washington, D.C.

Examines direct and secondary fire damage and estimates the seriousness of each form of injury, the immediate loss and indirect cost, and surveys the effect of losses on the future timber supply and on the forest management problem.

1717. Show, S. B., and E. I. Kotok.
1925. *Fire and the forest (California pine region).* U.S. Dep. Agric. Dep. Circ. No. 358, 20 p. Gov. Print. Off., Washington, D.C.

Assesses fire damage and concludes that fires have led to a steadily accelerating damage and forest deterioration, and that existing difficulties will increase unless virtual fire exclusion can be put into effect.

1718. Show, S. B., and E. I. Kotok.
1929. *Cover type and fire control in the National Forests of northern California.* U.S. Dep. Agric. Dep. Bull. 1495, 36 p. U.S. Gov. Print. Off., Washington, D.C.

Study of the nine major cover types of the California pine region reveals distinct and characteristic differences between them in their influence upon risk of fire starting, available fuel, type of fire, rate of spread of fire, ease of control, and accessibility of fire.

1719. Show, S. B., and E. I. Kotok.
1930. *The determination of hour control for adequate fire protection in the major cover types of the California pine region.* U.S. Dep. Agric. Tech. Bull. No. 209, 47 p. U.S. Gov. Print. Off., Washington, D.C.

Analyzes the speed-of-attack factor designed to hold burned acreage to an accepted minimum.

1720. Show, S. B., George M. Gowen, J. R. Curry, and A. A. Brown.
1937. *Planning, constructing, and operating forest-fire lookout systems in California.* U.S. Dep. Agric. Circ. No. 449, 56 p. U.S. Gov. Print. Off., Washington, D.C.

Explains the methods and techniques in developing a lookout system including visible-area mapping, construction of the observation facility, selection of personnel and the use of equipment.

1721. Show, S. B., and E. I. Kotok.
1937. *Principles of forest-fire detection on the National Forests of northern California.* U.S. Dep. Agric. Tech. Bull. No. 574, 32 p. U.S. Gov. Print. Off., Washington, D.C.

Determines that direct visibility and the continuous service of a primary lookout system is essential for fire protection on known risk areas.

1722. Show, S. B., C. A. Abell, R. L. Deering, and P. D. Hanson.
1941. *A planning basis for adequate fire control on the southern California National Forests.* Fire Control Notes 5(1):1-59.

Defines the problem of fire control planning and makes specific fire presuppression and suppresison recommendations to reduce losses in watersheds.

1723. Smith, Harvey H., and John P. Burke.
1952. *Keep your ax handle tight.* Fire Control Notes 13(3):4-6.

Suggests the use of softwood instead of metal wedges to secure handles to axe heads for fireline use.

1724. Stein, Andrew M., John G. Sullivan, and Francis W. Murray.
1973. *Physical models of fires and their associated environment.* Rand Paper, P-5049, 14 p., illus., Rand Corp., Santa Monica, Calif.

Proposes models for predicting and studying the dynamics of flow surrounding the source of a disturbance.

1725. Storey, Theodore G.
1965. *Estimating the moisture content of fuel moisture indicator sticks from selected weather variables.* U.S. Forest Serv. Res. Paper PSW-26, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Moisture content of 1/8-inch thick basswood slats can be determined with approximately equal precision in the critical low moisture range by equation or by weighing at danger stations.

1726. Storey, Theodore G., and Leon W. Cooley, Jr.
1967. *Air tankers in southern California fires . . . effectiveness in delivering retardants rated.* U.S. Forest Serv. Res. Note PSW-155, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Air tanker experts numerically rated 12 models of fixed-wing tankers and light helitankers for effectiveness in 21 typical environmental situations.

1727. Storey, Theodore G., D. Ross Carder, and Ernest T. Tolin.
1969. *INFORMAP . . . a computerized information system for fire planning and fire control.* USDA Forest Serv. Res. Paper PSW-54, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A prototype for planning applications which has been developed and tested is programmed in Fortran IV for the IBM 7040 computer, and displays information in tabular, narrative, or graphic form.

1728. Storey, Theodore G.
1972. *FOCUS: a computer simulation model for fire control planning.* Fire Technol. 8(2):91-103, illus.
Describes a system for evaluating forest fire control plans by using computer simulation.

1729. Swersey, Richard J.
1963. *Parametric and dynamic programming in forest fire control models.* Res. Rep. ORC 63-8, 24 p. Univ. Calif. Oper. Res. Center, Berkeley, Calif.
Describes the construction and application of decision rules for choosing suppression forces sent to a fire, given the essential fire characteristics, relative effectiveness of the forces, and the attack time.

1730. Swersey, Richard J.
1964. *Simultaneous parametric programs.* Oper. Res. 12(5):781-783, illus.
A special type of nonlinear programing problem is described which is convertible to a linear programing problem with simultaneously parametric righthand sides and objective function.

1731. Tauxe, G. J., and R. L. Stoker.
1951. *Analytical studies in the suppression of wood fires.* Am. Soc. Mech. Eng. Trans. 73(7):1005-1020.
Studies the instantaneous interfacial temperatures that occur when a water drop hits the surface of burning wood, and investigates, using a computer, simulated thermal behavior of burning wood as it is extinguished by surface cooling, penetration cooling, and oxygen dilution.

1732. Tolin, Ernest T., James B. Davis, and Conrad Mandt.
1969. *Automated forest fire dispatching—a progress report.* Fire Technol. 5(2):122-129, illus.
A dispatch model using an efficient algorithm for determining minimum travel routes for fire equipment has been developed.

1733. U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Stn.
1962. *Forest fire laboratory, Riverside, California.* 9 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Briefly describes facilities and lines of work planned at the laboratory.

1734. U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Stn.
1963. *Guidelines for fuel-breaks in southern California. Fuel-Break Rep. No. 9.* 25 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Outlines need for and methods of modifying natural brush fuels on strategic areas, called fuel-breaks, to break up expanses of chaparral and ease the fire control job.

1735. U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Stn.
1958. *Burning index computing tables.* 10 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Gives tables used to compute the burning index from fire weather observations.

1736. U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Stn.
1958. *California fire danger rating.* 28 p., illus. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Provides instructions and procedures for making fire weather observations, computing, and using the burning index in the California Fire Danger Rating System.

1737. Vargo, Louis G.
1967. *Optimum suppression tactics—a model and some theories.* Fire Technol. 3(1):17-19, 50-51.
Presents an analytical model of tactical decisionmaking for wildland fire suppression, which emphasizes the control line concept.

1738. Wagener, Willis W.
1961. *Past fire incidence in Sierra Nevada forests.* J. For. 59(10):739-748, illus.
A review of age counts of fire wounds in incense-cedar and white fir on the west slope indicates that fires in the virgin forests there occurred at average intervals of 8 to 10 years at a given location, before the establishment of the National Forests.

1739. Waklee, F. W., H. Shields and C. C. Wilson.
1957. *The helicopter—a new member of the hose-lay team.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 129, 11 p., illus. Berkeley, Calif.
Summarizes results of 1957 hose lay tests conducted over a 2-mile course and demonstrates the role helicopter can play in a long hose lay operation.

1740. Waklee, F. W., H. Shields, and C. C. Wilson.
1958. *The helicopter joins the hose-lay team.* Fire Control Notes 19(2):88-90, illus.[4]
Describes how helicopters can supplement ground equipment in laying fire hose over different types of vegetation.

1741. Wallis, James R., Kenneth L. Bowden, and J. D. Lent.
1963. *Area burned by wildfire in California watersheds,*

1940-1959. U.S. Forest Serv. Res. Note PSW-30, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Discusses the fires in 522 watersheds and 110 hydrographic regions, the data sources and characteristics.

1742. Ward, Franklin R., John D. Dell, and William C. Wood.
1968. *New trailer-mounted fire retardants mixer successfully field tested.* Fire Control Notes 29(3):15, illus.
A new mixer, field tested on slash burns in the Forest Service's Pacific Northwest Region, performed satisfactorily from roads and when towed on tractor firelines.

1743. Warren, John R.
1975. *Telemetering infrared imagery from aircraft to fire camp.* Fire Manage. 36(4):8-10.
Reports first successful use on Sept. 21, 1974, in the Angeles National Forest.

1744. White, Verdie E., and Lisle R. Green.
1967. *Fuel-breaks in southern California, 1958-1965.* 33 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Wildland firefighting agencies have cleared brush on 120 fuel-breaks, totaling 500 miles long and 13,800 acres.

1745. Wilson, Carl C.
1957. *A bird's eye view of forest fire research in the United States.* Pulp and Paper Mag. Can., Woodl. Sec., Oct. 1957:2.
Briefly summarizes prevention, suppression, and basic studies.

1746. Wilson, Carl C.
1957. *Helitack.* Pulp and Paper Mag. Can., Convention Issue. 1957:384-388.
Reports helicopter use on forest fires in Canada and United States since 1946.

1747. Wilson, Carl C.
1957. *New techniques in forestry. Chemicals retard forest fires.* No. Calif. Sec. Soc. Am. For. Proc. 1956:22-24.
A preliminary report on use of sodium calcium borate on forest fires.

1748. Wilson, Carl C.
1958. *Control of aircraft on forest fires.* Fire Control Notes 19(2):35-39.
Describes the functions necessary for safely controlling a complex operation of aircraft on forest fires and suggests one way of fitting these functions into the over-all fire control organization.

1749. Wilson, Carl C.
1961. *Are land managers making the best use of chemicals for forest fire fighting?* West. Fire Res. Comm. Proc. 1960:15-17.
Defines "fire retardants" and "fire suppressants" and outlines their development from 1821-1960.

1750. Wilson, Carl C., and Jerry R. Nilsson.
1962. *Forest fire research in California, an annotated bibliography, 1923-1961.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 75, 48 p. Berkeley, Calif.
The 236 items include all written material on Forest Service fire research in California.

1751. Wilson, Carl C., and Thomas K. McGuire.
1963. *Chemical fire retardants and fire control.* Soc. Am. For. Proc. 1962:60-62, illus.
The paper lists seven positive and seven negative characteristics of 'ideal retardants' and compares the characteristics of several candidate materials for use in fire control.

1752. Wilson, Carl C.
1964. *Chemicals for aerial attack on forest fires.* Rep. Fourth Agric. Aviat. Res. Conf., p. 46-50. U.S. Dep. Agric., Agric. Res. Serv.
Reviews history of air attack and research and development activities as of mid-1962.

1753. Wilson, Carl C., and John D. Dell.
1971. *The fuels buildup in American forests: a plan of action and research.* J. For. 68(8):471-475, illus.
Describes some of the more conspicuous fuel problems, evaluates what can be done about them with our present knowledge, and outlines high-priority research needs.

1754. Wilson, Carl C.
1974. *Where do we go from here?* Proc. Symp. on Living with the Chaparral, Riverside, Calif., 1973:201-206.
A fuel management and hazard reduction action committee has been set up, along with other groups, to seek solutions to California's wildland fire problems.

Fire Prevention

1755. Bernardi, Gene C.
1970. *Three fire prevention television films varying in "threat" content . . . their effectiveness in changing attitudes.* USDA Forest Serv. Res. Paper PSW-63, 26 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The hypotheses, that the films tested would elicit the emotions intended and that the film intended to have the strongest threat would be the most effective in producing positive attitude changes, were not confirmed.

1756. Bernardi, Gene C.
1973. *Fire prevention film spots for television . . . narrator influence on knowledge and attitude change.* USDA Forest Serv. Res. Paper PSW-94, 14 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
TV spots, with young people portrayed, were more effective in teaching proper fire practices in a classroom situation than they were in the normal television-viewing situation for which they were intended.

1757. Bernardi, Gene C.
1974. *Fire prevention film spots . . . reception by television public service directors.* USDA Forest Serv. Res. Note PSW-296, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Most of the public service directors of television stations who were interviewed rated fire prevention commercials positively for their technical quality, ability to communicate, and interest to the intended audience.

1758. Bernardi, Gene C.
1974. *Fires caused by equipment use during critical fire weather in California, 1962-1971.* USDA Forest Serv. Res. Note PSW-289, 6 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Major fires from autos and trucks were relatively frequent, but most started during noncritical fire weather, harvesters caused major fires during both critical and noncritical weather.

1759. Chandler, Craig C.
1956. *Integrating prevention into fire control planning.* Fire Control Notes 17(2):6-7.
Suggests a need for major reevaluation of fire-control planning methods in order to integrate fire prevention in organization plans.

1760. Chandler, Craig C.
1960. *How good are statistics on fire causes?* J. For. 58(7):515-517.
Analysis of the accuracy of published statistics of fire causes shows that most fires of unknown origin are called "smoker," nearly all fires of unknown origin are attributed to "outsiders," and the average accuracy for all man-caused fires was 79 percent.

1761. Chandler, Craig C.
1960. *Measuring the people threat to forest management.* Soc. Am. For. Proc. 1959:131-132.
Thirty-eight owners of 2½ million acres of private timberland in California were polled—recreation was encouraged on 200,000 acres, prohibited on 400,000 acres, and "tolerated" on the remainder.

1762. Chandler, Craig C., and James B. Davis.
1960. *What do people know about fire prevention?* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 50, 4 p. Berkeley, Calif.
A survey showed that local residents had more fire prevention knowledge than forest visitors and that knowledge of fire prevention paralleled quite closely general education level indicated by occupation.

1763. Chandler, Craig C., and James B. Davis.
1961. *What do people know about fire prevention?* Fire Control Notes 22(1):9-12.
See item 1762 above.

1764. Christiansen, John R., William S. Folkman, J. Lorraine Adams, and Pamela Hawkes.
1969. *Forest-fire prevention knowledge and attitudes of residents of Utah County, Utah, with comparisons to Butte County, California.* Soc. Sci. Res. Bull. 5, 26 p., illus. Dep. Soc., Coll. Soc. Sci., Brigham Young Univ., Provo, Utah.
Knowledge about fire prevention was higher among the Utah population than among a comparable California population with frequent forest visitors, especially hunters and fishermen, scoring better than average on a knowledge test.

1765. Christiansen, John R., and William S. Folkman.
1971. *Characteristics of people who start fires . . . some preliminary findings.* USDA Forest Serv. Res. Note PSW-251, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes characteristics of individuals and employers held responsible for starting forest fires in National Forests of the Intermountain and California Regions.

1766. Davis, James B., and Craig C. Chandler.
1960. *What people think about forest fire law enforcement.* U.S. Forest Serv. Pacific Southwest Forest

and Range Exp. Stn. Misc. Paper 51, 4 p. Berkeley, Calif.
A study indicated that fire law violators had a high traffic citation frequency and a low knowledge of forest surroundings.

1767. Davis, James B., and Craig C. Chandler.
1961. *What people think about fire law enforcement.* Fire Control Notes 22(1):13-15.
See item 1766 above.

1768. Folkman, William S.
1963. *Levels and sources of forest fire prevention knowledge of California hunters.* U.S. Forest Serv. Res. Paper PSW-11, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The hunter population, which consists mainly of males 30-50 years of age from the smaller urban centers (under 25,000 in population), had a generally high level of knowledge concerning forest fire prevention, but their knowledge was weak in some pertinent areas.

1769. Folkman, William S.
1964. *Effect of color on recall in fire prevention signing.* U.S. Forest Serv. Res. Note PSW-41, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A change of background color on prevention signs from the usual black on light yellow to bright, high intensity orange did not improve recall.

1770. Folkman, William S.
1965. *Motorists' knowledge of the 'No Smoking' ordinance in southern California.* U.S. Forest Serv. Res. Note PSW-72, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports that 29 percent of motorists interviewed in an area where smoking was restricted were misinformed about or did not know of the regulation, and relates familiarity with the regulation to whether the motorist smoked, frequency of use of the area, and place of residence.

1771. Folkman, William S.
1965. *Residents of Butte County, California: their knowledge and attitudes regarding forest fire prevention.* U.S. Forest Serv. Res. Paper PSW-25, 32 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Fire prevention knowledge and attitude levels were related to the degree of exposure to high risk forest environment and to the socio-economic characteristics of the population.

1772. Folkman, William S.
1965. *Signing for the 'No Smoking' ordinance in southern California.* U.S. Forest Serv. Res. Note PSW-71, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Finds that symbolic signs had high visibility and were correctly interpreted by most travelers.

1773. Folkman, William S.
1966. *"Children-with-matches" fires in the Angeles National Forest area.* U.S. Forest Serv. Res. Note PSW-109, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Finds that the incidence of this type of forest fire poses a threat to the Angeles National Forest and reports some data on the characteristics of the offenders.

1774. Folkman, William S.
1966. *Forest fires as accidents: an epidemiological approach to fire prevention research.* Proc. 56th West. For. and Conserv. Assoc. Conf. 1965:136-142, illus.
Suggests relating forest fire starts to the more general class of phenomena—accidents—so as to capitalize on research already done by those working in this area.

1775. Folkman, William S.
1966. *Modifying the communicative effectiveness of fire prevention signs.* U.S. Forest Serv. Res. Note PSW-104, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports on a test in which four adult special interest groups were exposed to a picture of a commonly used Forest Service sign "America needs productive forests."

1776. Folkman, William S.
1967. *Evaluation of fire hazard inspection procedures in Butte County, California.* U.S. Forest Serv. Res. Note PSW-145, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Suggests that fire law inspection is as much fire prevention education and engineering as it is law enforcement.

1777. Folkman, William S.
1967. *Latest developments in fire prevention research.* West. Forest Fire Comm., West. For. and Conserv. Assoc. Proc. 1967:11-18.
Summarizes work at the U.S. Forest Service's Pacific Southwest Forest and Range Experiment Station in research concerned with human factors in man-caused forest fire problems.

1778. Folkman, William S.
1968. *Follow-up evaluation of fire hazard inspection procedures . . . Butte County, California.* U.S.

Forest Serv. Res. Note PSW-169, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A study was repeated to assess effectiveness of fire hazard inspection procedures in securing compliance with safety requirements.

1779. Folkman, William S.
1968. *Problem debris burners in western Oregon.* 27 p. Oregon State For. Dep.
To aid in the development of more effective fire prevention measures, the characteristics of problem-debris burners were compared with their neighbors who had no record of creating such a problem.

1780. Folkman, William S., Robert J. McLaren, and John R. Christiansen.
1968. *Public responsibility for natural resources . . . attitudes of Utah County, Utah residents.* U.S. Forest Serv. Res. Note PSW-165, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Social class was not a significant determinant of attitude, but age, marital status, length and location of residence, and awareness of forest problems were related to concern for negligence and vandalism.

1781. Folkman, William S.
1972. *Children caused fires—how to prevent them.* Proc. Seventh Annu. Meet. Middle Atlantic Interstate For. Fire Prot. Compact, Chevy Chase, Maryland 1972:27-39.
Discusses what is known about why children start fires and what can be done to reduce the severity of the problem.

1782. Folkman, William S., and Jean Taylor.
1972. *Fire prevention in California's Riverside County Headstart Project . . . an evaluation.* USDA Forest Serv. Res. Paper PSW-79, 29 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports an evaluation of the effectiveness of a specially designed series of fire prevention lessons when used with preschool children in the Headstart Program.

1783. Folkman, William S.
1972. *Studying the people who cause forest fires.* In *Social behavior, natural resources, and the environment.* p. 44-64. Harper and Row Publishers, Inc., New York.
Focuses on research problems to be faced in studying aspects of identifying and characterizing forest users who are considered high risks.

1784. Folkman, William S.
1973. *Fire prevention in Butte County, California . . . evaluation of an experimental program.* USDA Forest Serv. Res. Paper PSW-98, 23 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The number of fires in the study area dropped during the period of most intensive prevention activity (1968 and 1969), but analysis was not conclusive in showing this drop to be due to the experimental program rather than other, non-controlled variables.

1785. Folkman, William S.
1973. *Roadside fire prevention signs . . . a restudy of their effectiveness.* USDA Forest Serv. Res. Note PSW-282, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The effectiveness of fire prevention signs studied after exposure of 6 years to the public was not diminished.

1786. Folkman, William S.
1975. *Butte County, California, residents: their knowledge and attitudes about forest fires reassessed.* USDA Forest Serv. Res. Note PSW-297, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Identifies youths and people over 65 years of age, with limited education and income, as the target groups for special attention in fire prevention work.

1787. Folkman, William S.
1975. *Radio and television use in Butte County, California: application to fire prevention.* USDA Forest Serv. Res. Paper PSW-106, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Although most people in Butte County listen to the radio or watch television, they differ widely in the way they use both of these media.

1788. Gladen, Frank H., and Helen S. Carkin.
1970. *A study of the effectiveness of specific teaching of conservation to children in selected elementary schools of Butte County, California.* Calif. J. Ed. Res. 21(4):152-169.
The experimental instrumental materials had their greatest impact in the kindergarten and first grade and had less impact in the second and third grades.

1789. Herrman, W. W.
1962. *The California hunter: levels and sources of forest fire prevention knowledge.* 225 p. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Concludes that while California hunters are generally well informed about fire prevention matters, they do not generally understand the behavior of forest and wildland fires.

1790. Herrman, W. W., and others.
1962. *Signing study, phase I: A method for determining the semantic differential in responses to various stimuli.* School of Public Admin., Univ. South. Calif.
Results from a study that used student subjects and a variety of signs, indicated that words and symbols could be combined to maximize emission of fire-related concepts.

1791. Ruckel, Gail J., and William S. Folkman.
1965. *Roadside fire prevention signs—standard and new designs compared.* U.S. Forest Serv. Res. Note PSW-65, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Results of the impact and recall value of a set of regularly used U.S. Forest Service fire prevention signs compared with that of a set of improvised signs showed the improvised signs had greater impact.

1792. Sarapa, Adam, and William S. Folkman.
1970. *Fire prevention in the California Division of Forestry . . . personnel and practices.* USDA Forest Serv. Res. Paper PSW-65, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Examines the way in which employees interpret their roles, and relates these interpretations to the functioning of the division's fire prevention program.

1793. Siegelman, Ellen Y., and William S. Folkman.
1971. *Youthful fire-setters . . . an exploratory study in personality and background.* USDA Forest Serv. Res. Note PSW-230, 6 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Multiple fire-setters were found to be characterized by a number of associated problems, such as excessive activity, aggression, and psychosomatic difficulties, rather than one particular distinguishing characteristic.

1794. University of Southern California.
1965. *Children with matches fires in Angeles National Forest and adjacent jurisdictions . . . a preliminary analysis.* 53 p. Univ. South. Calif. Sch. Public Adm. Administr. Dyn. Res. Proj.
Finds that during a 5-year period, the Angeles National Forest had nearly 10 fires annually that were caused by children playing with matches.

Fire Behavior

1795. Abell, C. A.
1940. *Rates of initial spread of free-burning fires on the national forests of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 24, 26 p. Berkeley, Calif.
Data on the rates of spread of more than 9500 fires is graphically summarized.

1796. Arnold, R. K., and C. C. Buck.
1952. *East Bay Hills grass-fuel fire spread index.* 7 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Shows by means of indexes the relative rates at which fire will spread under combinations of temperature, relative humidity, and wind velocity.

1797. Arnold, R. K., and C. C. Buck.
1954. *Blow-up fires—silviculture or weather problems.* J. For. 52(6):408-411.
Identifies and describes some possible situations which may cause 'blow-ups' on fires as a step toward their understanding and control.

1798. Auvil, Clifford J.
1973. *Fire environmental test chamber, its design and development.* USDA Forest Serv. Res. Note PSW-280, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The test chamber at the U.S. Forest Service's Forest Fire Laboratory, Riverside, California, can duplicate under controlled conditions the key factors that affect the flammability of wildland fuels.

1799. Broido, A.
1967. *Observations during Project Flambeau experimental fire 460-7-66, June 14, 1966.* Def. At. Spt. Agency DASIAC Spec. Rep. 59 (Oct. 1967):413-417.
Transcription of tape-recorded observation by the author of the Project Flambeau experimental fire of June 14, 1966.

1800. Bruce, H. D., W. Y. Pong, and W. L. Fons.
1961. *The effect of density and thermal diffusivity of wood on the rate of burning of wood cribs.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 63, 14 p., illus. Berkeley, Calif.
Results from experimental data for five species of wood, each of several density classes, indicate that the rate of fire spread decreased with increasing density.

1801. Buck, Charles C.
1950. *Fire behavior in relation to factors of environment.* In *Short course on range improvement,* p. 66-

71. Hunt Hall Auditorium, Univ. of Calif., Davis. January 31, February 1 and 2, 1950.
Reports that fire intensity and rate of spread are dependent on five factors: "character" of fuel, fuel moisture content, fuel temperature, wind velocity, and topography.

1802. Bush, A. F., J. J. Leonard, and W. H. Yundt.
1969. *Gas analyses in large fire experiments.* In *Project Flambeau . . . an investigation of mass fire (1964-1967). Final report—volume III: Appendices.* p. 33-90, illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports data on life hazard in the open (fuel bare) regions between piles or burning units in experimental fires and in regions which might serve as shelter locations.

1803. Chandler, Craig C., and Clive M. Countryman.
1959. *Use of fire behavior specialists can pay off.* Fire Control Notes 20(4):130-132.
Lists the requirements for adequate operation of a fire behavior team on campaign fires, and outlines the services the team can provide if properly organized.

1804. Chandler, Craig C.
1961. *Fire behavior of the basin fire.* 84 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Gives a detailed history of fire behavior as affected by fuels, weather and topography, and examines five specific fire behavior anomalies in detail.

1805. Chandler, Craig C., Theodore G. Storey, and Charles D. Tangren.
1963. *Prediction of fire spread following nuclear explosions.* U.S. Forest Serv. Res. Paper PSW-5, 110 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Information on rate, duration, and extent of spread of such fires was used to determine the conditions when fires would not spread significantly and the conditions when fires would be extinguished in the absence of effective firefighting action.

1806. Chandler, Craig C.
1963. *A study of mass fires and conflagrations.* U.S. Forest Serv. Res. Note PSW-22, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes some major results from a study reported in full by Chandler, Storey, and Tangren.

1807. Chandler, Craig C., and Mark J. Schroeder.
1965. *Probability of effective post-attack fire fighting in wildlands.* U.S. Off. of Civ. Def. Res. Rep. 10, 9 p.
Gives the probabilities of the occurrence of four classes of fire behavior, by months, for 14 regions of the United States in the event of nuclear attack.

1808. Countryman, Clive M., and Mark J. Schroeder.
1960. *Fire environment—the key to fire behavior.* Proc. Fifth World For. Congr. Vol. 2, Seattle, Wash., 1960:860-863.
Points out that the fire environment, which is often affected by silvicultural and wildland management practices, is related to fire behavior.

1809. Countryman, Clive M., and Craig C. Chandler.
1963. *The fire behavior team approach in fire control.* Fire Control Notes 24(3):56-60, illus.
The need for precise information on fire behavior and fire weather has focused attention on a gap between the science of weather forecasting and the science of fire control, resulting in the concept of a fire behavior team.

1810. Countryman, Clive M.
1964. *Mass fires and fire behavior.* U.S. Forest Serv. Res. Paper PSW-19, 53 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Gives preliminary results from a series of large-scale test fires, including results on airflow patterns in and around the fire, flame temperatures, noxious gas output, and convection column characteristics.

1811. Countryman, Clive M.
1965. *Mass fire characteristics from large scale tests.* Fire Technol. 1:303-317.
Data obtained in a series of fire tests simulating urban conditions include airflow patterns in and around the fire, temperature of flames and gases, noxious gas output, pressures in and around the fire, and convection column characteristics.

1812. Countryman, Clive M.
1966. *The concept of fire environment.* Fire Control Notes 27(4):8-10, illus.
Fire environment is the current state of each of the components of fire environment and their interrelationships with each other and with fire, which determines the behavior and characteristics of a fire at any moment.

1813. Countryman, Clive M.
1967. *Thermal characteristics of pinyon pine and juniper fuels used in experimental fires.* Def. At. Spt. Agency DASIAC Spec. Rep. 59 (Oct. 1967):309-319.
Pinyon pine and juniper trees were analyzed to determine such physical characteristics as amount of material of different sizes, total surface area, surface-to-volume ratio of fuel particles, heating values of various parts of the tree, ash content, and amount of ether soluble constituents.

1814. Countryman, Clive M.
1967. *Weight loss platforms to measure burning rate.* Def. At. Spt. Agency DASIAC Spec. Rep. 59 (Oct. 1967):269-284.
In the June 14, 1966 experimental fire simulating an urban area of about six city blocks; 15- by 15-foot weighing platforms supported by load cells were used to measure burning rates.

1815. Countryman, Clive M.
1969. *Project Flambeau . . . an investigation of mass fire (1964-1967). Final report—volume I.* 68 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes the work of Project Flambeau during the period 1964-1967; outlines present knowledge of mass fires.

1816. Countryman, Clive M., and Charles W. Philpot.
1970. *Physical characteristics of chamise as a wildland fuel.* USDA Forest Serv. Res. Paper PSW-66, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Sixteen chamise shrubs, an important fuel in southern California, were analyzed for the main fuel properties now known to affect fire behavior.

1817. Countryman, Clive M.
1971. *Firewhirls—why, when, and where.* 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Most fire whirls are small and short-lived, but occasionally one will become large and strong enough to do tornado-like damage to forests and structures.

1818. Countryman, Clive M.
1972. *The fire environment concept.* 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Explores the general nature of fire environment—what it is composed of, how it varies, and how fire fits into the environmental picture.

1819. Countryman, Clive M.
1974. *Moisture in living fuels affects fire behavior.* Fire Manage. 35(2):10-14, illus.
The moisture content in living chaparral usually follows the same general pattern each year, but the differences from year to year affect fire behavior and decisions in fire control and prescribed burning.

1820. Countryman, Clive M.
1975. *Heat—its role in wildland fire. Part I. The nature of heat.* 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Examines some of the basic characteristics of the heat segment of the fire triangle—the nature of heat itself.

1821. Curry, John R.
1936. *Fire behavior studies on the Shasta Experimental Forest.* Fire Control Notes 1:12-13.
Analysis of data from over 300 small fires indicates that wind, moisture content and time are the basic factors which control fire spread.

1822. Curry, John R., and Wallace L. Fons.
1938. *Rate of spread of surface fires in the ponderosa pine type of California.* J. Agric. Res. 57(4):239-267.
Empirical formulas derived from curves of moisture, wind, and slope influences permit estimates of rate of perimeter increase or total perimeter at any time interval within the limits of the data.

1823. Curry, John R., and Wallace L. Fons.
1940. *Forest-fire behavior studies.* Mech. Eng. 62(3):219-225.
Examines fuel moisture, wind velocity, and relative humidity with the aim of integrating these factors into a series of indexes expressing the chance of fires starting, rapidity of spread, and the type of organization needed to cope with current fire danger.

1824. Davis, James B., and Craig C. Chandler.
1965. *Vortex turbulence—its effect on fire behavior.* Fire Control Notes 26(1):4-7, illus.
Describes the problems that the air tanker pilot should be aware of in connection with vortex turbulence, and its causes and affects on the air tanker, on other aircraft, and on ground fire.

1825. Dell, John D., and Melvin K. Hull.
1966. *A fire behavior team field unit.* Fire Control Notes 27(3):6-7.
Describes a trailer unit designed to facilitate the operations of fire behavior teams on wildfires.

1826. Dell, John D.
1966. *The fire behavior team in action—the Coyote Fire, 1964.* Fire Control Notes 27(1):8-10, 15.
Illustrates, by example, the services a fire behavior team is able to provide to fire control organizations.

1827. Fons, W. L.
1940. *An Eiffel type wind tunnel for forest research.* J. For. 38(11):881-884.
Presents specifications for a low velocity wind tunnel used in basic combustion studies providing wind conditions of constant direction and controlled intensity.

1828. Fons, W. L.
1946. *Analysis of fire spread in light forest fuels.* J. Agric. Res. 72(3):93-121.

Derives equations for rate of fire spread in homogeneous and heterogeneous fuel beds taking into account the physical characteristics of the fuel particles, the arrangement of the bed, and the pertinent attributes of the atmosphere.

1829. Fons, W. L.
1950. *Heating and ignition of small wood cylinders.* Ind. and Eng. Chem. 42(10):2130-2133.
Studies the effects of initial temperature, size, moisture content, and heating rate on the ease of ignition of wood cylinders.

1830. Fons, W. L., H. D. Bruce, and W. Y. Pong.
1960. *A steady-state technique for studying the properties of free-burning wood fires.* Fire Res. Abstr. and Rev. 2(1):28-30.
Describes the development of a suitable bed of solid fuel and study technique for a laboratory study with the ultimate objective of determining model laws for properties of wood fires, including rate of spread.

1831. Fosberg, Michael A.
1967. *Evaluation of the natural length scale in mass fires.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:353-359.
Describes a simplified model of convection energetics devised to examine the dynamic consequences of Countryman's transition zone of mass fires.

1832. Gaines, Edward M.
1967. *Background and general progress of Project Flambeau.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:240-242.
The Project Flambeau program has been re-oriented to stress analysis of data and development of hypotheses and models.

1833. Gaines, Edward M.
1967. *Project Flambeau experimental fire of June 14, 1966.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:243-246.
Describes an experimental fire, 8 miles east of Mono Lake near the California-Nevada state line, conducted by the U.S. Forest Service for the U.S. Office of Civil Defense.

1834. Gaines, Edward M.
1967. *Project Flambeau panel summary.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:421.
Suggests the need to consider whether measurements made in experimental fires are adequate, and whether other types of measurements should be made in future experimental fires.

1835. Jones, Donald C., and A. Broido.
1971. *Apparatus for determining glowing combustibility of thin fuels.* J. Fire and Flammability 2:77-86, illus.
Leaflike samples, approximately 8 cm. in diameter, are held at the end of a mechanical arm which reproducibly controls sample movement during the ignition and burning process.

1836. McCarter, R. J., and A. Broido.
1965. *Radiative and convective energy from wood crib fires.* Pyrodynamics 2(1):65-85.
Steady-state fires burning through laboratory-scale cribs of western hemlock sticks confirmed results predicted from similar studies, that nearly half of the heat of combustion leaves the fire area as radiation, and roughly half of this radiated energy emanates from the advancing flame zone.

1837. McCarter, R. J., and A. Broido.
1967. *Radiant energy dosimeter for field use.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:256-268.
Reports details on the original meter design, describes the crude results obtained during an experimental fire, and indicates some of the limitations in such an instrument.

1838. McCarter, R. J., and A. Broido.
1967. *A radiant energy dosimeter for field use.* Fire Technol. 3(3):213-224, illus.
A simple meter was developed to record specific energy input during experimental fire.

1839. McCarter, R. J.
1967. *Thermal radiation measurements of Project Flambeau.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:320-328.
Summarizes radiometer measurements obtained on the margins of Project Flambeau test fires.

1840. Murray, John R., and Clive M. Countryman.
1970. *Cantilever scales for measuring weight changes.* USDA Forest Serv. Res. Note PSW-206, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A weighing device using a cantilever beam and a load cell has been constructed to give an electrical readout of weight changes with time.

1841. Murray, John R., Lee I. Northcutt, and Clive M. Countryman.
1971. *Measuring mass loss rates in free burning fires.* Fire Technol. 7(2):162-169, illus.
A weighing system using a large insulated platform supported on load cells was designed to monitor and record

mass loss of large quantities of fuel over time.

1842. Neuns, Alva G.
1950. *A training course in fire behavior.* 23 p. U.S. Forest Serv., San Francisco, Calif.
Short course on the physical factors involved in fire, and how those factors behave under field conditions.

1843. Nord, Eamor C., and Clive M. Countryman.
1972. *Fire relations.* In *Wildland shrubs—their biology and utilization.* USDA Forest Serv. Gen. Tech. Rep. INT-1, p. 88-97, illus. Intermountain Forest and Range Exp. Stn., Ogden, Utah.
The effect of chemical composition on fuel moisture, along with seasonal changes in chemical composition are currently being investigated at the Forest Fire Laboratory in Riverside.

1844. O'Regan, William G.
1967. *Data, statistics, and experimental design on Project Flambeau.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:346-352.
Reports preliminary analyses of small sets of data from earlier test fires and progress in adapting certain statistical theory to analysis of some aspects of fire behavior.

1845. Palmer, Thomas Y.
1969. *Project Flambeau . . . an investigation of mass fire (1964-1967). Final report—volume II. Catalogue of Project Flambeau fires, 1964-1967.* 53 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes, in catalogue form, the data available from nine experimental fires conducted by Project Flambeau during the period 1964-1967.

1846. Palmer, Thomas Y., and Lee I. Northcutt.
1975. *Convection columns above large experimental fires.* Fire Technol. 11(2):111-118, illus.
The rate of rise of the convection columns above the Project Flambeau test fires depended upon the average atmospheric temperature lapse rate in the lower 1000 meters.

1847. Palmer, Thomas Y., and Clifford J. Auvil.
1975. *Recording wind velocity, direction, and temperature in fires by logarithmic technique.* USDA Forest Serv. Res. Note PSW-304, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A logarithmic data recording system has been devised which makes it easy to observe turbulent fluctuations from the mean in ratio form.

1848. Philpot, Charles W.
1965. *Temperatures in a large natural fuel fire.* U.S. Forest Serv. Res. Note PSW-90, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Temperatures in a large natural-fuel test fire were measured with bare, aspirated and shielded chromel-alumel thermocouples with values of at least 2650° F. obtained with the bare couples.

1849. Pirsko, Arthur R.
1961. *An alinement chart for perimeter increase of fires.* Fire Control Notes 22(1):1-4, illus.
Presents an alinement chart to eliminate arithmetical computations associated with studies of rate of fire spread.

1850. Scesa, S., and F. M. Sauer.
1954. *Possible effects of free convection on fire behavior—laminar and turbulent line and point sources of heat.* 47 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
A theoretical analysis of the transport of heat, mass, and momentum in forest fire convection zones.

1851. Sommers, William T.
1975. *Data requirements of mesoscale and toposcale models for mountainous terrain.* Proc. Third Symp. Meteorol. Obs. and Instrum. Feb. 10-13, 1975, Washington, D.C., p. 10-13.
Describes the types of data needed by mesoscale and toposcale models being developed to provide input to fire-spread modeling.

1852. Storey, Theodore G.
1969. *Preparation of test plots for fire behavior studies using wildland fuels to simulate urban conditions.* In *Project Flambeau . . . an investigation of mass fire (1964-1967). Final report—volume III: Appendices.* p. 1-14, illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes methods used to select the test site, clear the land, prepare the plots, and determine the amount of fuel for experimental fires.

1853. Storey, Theodore G.
1969. *Tree weights and fuel size distribution of pinyon pine and Utah juniper.* In *Project Flambeau . . . an investigation of mass fire (1964-1967). Final report—volume III: Appendices.* p. 15-32, illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The weight of trees was related to size and dimensions in determining distribution of fuel weight in the two tree species.

Fire Meteorology

1854. Britton, C. M., C. M. Countryman, H. A. Wright, and A. G. Walvekar.
1973. *The effect of humidity, air temperature, and wind speed on fine fuel moisture content.* Fire Technol. 9(1):46-55, illus.
Prediction equations were developed to express moisture loss (desorption) and moisture gain (absorption) for tobosa grass as a function of time.

1855. Coffin, Harry.
1959. *Effect of marine air on the fireclimate in the mountains of southern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 39, 30 p., illus. Berkeley, Calif.
The southerly wind component at San Diego shows seasonal change in the influx of marine air which in turn affects the incidence of wildland fires.

1856. Colson, D.
1956. *Wind survey.* 18 p., illus. U.S. Weather Bureau, and Station Fire Res. Staff for Firestop Exec. Comm.
Describes procedures and instrumentation developed for a 3-month intensive study of air movement in a typical mountain canyon and gives recommendations for future wind surveys.

1857. Countryman, Clive M., and P. H. Intorf.
1953. *A fire season severity index for California National Forests.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 14, 7 p. Berkeley, Calif.
Develops a fire season severity index based on fire danger ratings, and number and size of fires.

1858. Countryman, Clive M.
1953. *A pocket type humidity indicator for use in fire prevention and control.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 12, 1 p. Berkeley, Calif.
Detailed description of how to construct a colorimetric instrument to measure relative humidity.

1859. Countryman, Clive M.
1956. *Fire season severity in 1955 on the Klamath National Forest.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 103, 7 p., illus. Berkeley, Calif.
Discusses weather conditions in 1955, which produced the most severe burning conditions ever experienced on the Klamath National Forest, and shows how a severity index can be computed.

1860. Countryman, Clive M.
1956. *Old-growth conversion also converts fireclimate.* Soc. Am. For. Proc. 1955:158-160, illus.
Cutting a forest stand changes the local fire weather and therefore changes the fire-control job.

1861. Countryman, Clive M.
1957. *California fire-weather severity in 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note No. 118, 7 p., illus. Berkeley, Calif.
A survey of the fire-weather severity in northern California shows that the 1956 weather was easy as compared to a 5-year average, but in southern California the fire-weather index climbed rapidly to a high level, indicating a heavy fire load.

1862. Countryman, Clive M., and DeVer Colson.
1958. *Local wind patterns in Wildcat Canyon.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 28, 12 p., illus. Berkeley, Calif.
Shows some of the kinds of information that can be derived from fireclimate surveys.

1863. Countryman, Clive M., and Mark J. Schroeder.
1958. *Prescribed burn fireclimate survey 1-57.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 29, 14 p. Berkeley, Calif.
Describes the results of a survey in the lower foothills of the central Sierra Nevada and shows that there can be an increase in windspeed on the lee side of a fire under some conditions.

1864. Countryman, Clive M., and Mark J. Schroeder.
1959. *Prescribed burn fireclimate survey 2-57.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 31, 18 p., illus. Berkeley, Calif.
A survey in the foothills of the central Sierra showed that fire behavior, including the development of fire whirls, may follow closely the wind flow pattern of the area.

1865. Countryman, Clive M., and Mark J. Schroeder.
1959. *Prescribed burn fireclimate survey 3-57.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 34, 15 p., illus. Berkeley, Calif.
A survey in the central coast area of California showed the development of strong downslope winds during the afternoon with fire behavior following closely the predetermined wind flow pattern.

1866. Countryman, Clive M., and Mark J. Schroeder.
1959. *Prescribed burn fireclimate survey 4-57.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 35, 19 p., illus. Berkeley, Calif.
A survey in a steep-walled canyon in the Vaca mountains suggests that air flow pattern in such a topographic situation may be extremely complex and may occur in "layers".

1867. Countryman, Clive M., and Arthur R. Pirsko.
1962. *Fire weather severity for southern California in 1961.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 65, 6 p., illus. Berkeley, Calif.
Summarizes conditions that presented southern California fire-control agencies with the worst fire-control job in recent history.

1868. Countryman, Clive M., John R. Murray, and Charles W. Philpot.
1963. *An electronic fire weather station.* U.S. Forest Serv. Res. Note PSW-17, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A new electronic fire weather station automatically records wet and dry bulb temperatures, radiation, windspeed and direction, standard fuel-stick moisture content, and fine-fuel temperature at 6- or 30-minute intervals for 1 week without on-site attention.

1869. Countryman, Clive M.
1964. *The Los Angeles fires of March 16, 1964.* U.S. Forest Serv. Res. Note PSW-46, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes three fires in the mountains at the edge of Los Angeles which burned over 11,650 acres and the conditions which were attributive to the extensive damage.

1870. Countryman, Clive M., Michael A. Fosberg, Richard C. Rothermel, and Mark J. Schroeder.
1968. *Fire weather and behavior of the 1966 Loop Fire.* Fire Technol. 4(2):126-141, illus.
Describes the fire weather and fire behavior during the Loop Fire of November 1, 1966, in which 10 firefighters were killed, and 2 others died later.

1871. Countryman, Clive M., Morris H. McCutchan, and Bill C. Ryan.
1969. *Fire weather and fire behavior at the 1968 Canyon Fire.* USDA Forest Serv. Res. Paper PSW-55, 20 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes fire weather and fire behavior at the 1968 Canyon Fire in which seven Los Angeles firefighters and their foreman were fatally burned.

1872. Cramer, Owen P., and Ralph H. Moltzau.
1968. *Wind instrument mountings for above-the-cab lookout exposure.* USDA Forest Serv. Res. Note PSW-175, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The lookout tower offers a ready-made platform from which speed of the true unobstructed wind can be measured, then reduced to the equivalent of the 20-foot wind.

1873. Cramer, Owen P., and Robert E. Lynott.
1970. *Mesoscale analysis of a heat wave in western Oregon.* J. Appl. Meteorol. 9(5):740-759, illus.
The charts developed in this study permit a new look at summer fair-weather patterns in mountainous terrain.

1874. Cramer, Owen P.
1972. *Potential temperature analysis for mountainous terrain.* J. Appl. Meteorol. 11(1):44-50, illus.
The large-scale cross section and terrain surface analysis of potential temperature are presented as aids for study of mesoscale and finer weather variations.

1875. Cramer, Owen P.
1973. *Mesosystem weather in the Pacific Northwest—a summer case study.* Monthly Weather Rev. 101(1):13-23, illus.
Emphasizes the need for greater attention to mesoscale systems for identification and warning of important summer weather events.

1876. Dibole, Dean L.
1960. *The fireclimate survey trailer.* Fire Control Notes 21(4):116-120, illus.
Describes conversion of two-wheeled trailer to a mobile unit for carrying recording meteorological instruments used for fire environment studies, going fires, or anywhere where 24-hour recorded weather observations are needed.

1877. Edinger, James G., Roger A. Helvey, and David Baumhefner.
1964. *Surface wind patterns in the Los Angeles basin during 'Santa Ana' conditions.* 72 p., illus. Los Angeles: Dep. of Meteorol., Univ. Calif. at Los Angeles.
The surface wind field is presented first in statistical terms, percentage frequency of wind directions and mean wind speeds, and then as streamline analyses of individual situations.

1878. Fons, W. L.
1940. *Influence of forest cover on wind velocity.* J. For.

38(6):481-486.
Presents figures and equations based on observations of wind velocity in pine, brush, and grass cover types showing that simple relations exist between the velocities at different heights.

1879. Fosberg, Michael A., and Mark J. Schroeder.
1963. *A warm sea breeze.* U.S. Forest Serv. Res. Note PSW-18, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports results of two studies north of San Francisco Bay which showed that when the marine air layer is shallow, the sea breeze front could affect forest fire behavior adversely for fire control.

1880. Fosberg, Michael A.
1965. *A case study of the Santa Ana Wind in the San Gabriel Mountains.* U.S. Forest Serv. Res. Note PSW-78, 8 p., illus. Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.
Finds that Santa Ana wind structure varies between the high main ridges, the foothills, and the canyon bottoms and that each region is characterized by a typical pattern.

1881. Fosberg, Michael A., and Mark J. Schroeder.
1965. *An example of nighttime drying in the Santa Ana Mountains.* U.S. Forest Serv. Res. Note PSW-74, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Nighttime downslope winds through their effect on the marine layer, are the most satisfactory explanation for the decrease in moisture found in the humidity patterns near the 500 to 1000 meter level.

1882. Fosberg, Michael A., and Mark J. Schroeder.
1966. *Marine air penetration in central California.* J. Appl. Meteorol. 5(5):573-589, illus.
Three-dimensional analysis shows the sea-breeze front to be primarily a wind shift line, in which thermal discontinuity lags behind the shear line and becomes quasi-stationary in the afternoon.

1883. Fosberg, Michael A., Clyde A. O'Dell, and Mark J. Schroeder.
1966. *Some characteristics of the three-dimensional structure of Santa Ana Winds.* U.S. Forest Serv. Res. Paper PSW-30, 35 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Examines the three-dimensional structure of the Santa Ana through two case studies in California.

1884. Fosberg, Michael A.
1967. *Numerical analysis of convective motions over a mountain ridge.* J. Appl. Meteorol. 6(5):889-904.
Results from the numerical analysis of the observed data were compared with numerical simulations of valley winds and convection published in the meteorological literature.

1885. Fosberg, Michael A.
1969. *Airflow over a heated coastal mountain.* J. Appl. Meteorol. 8(3):436-442, illus.
Observations of airflow over the Santa Ana Mountains were analyzed by numerical techniques using the Boussinesq equations and their energy properties to define the terms computed from the observed data.

1886. Furman, R. William, and Robert S. Helfman.
1973. *A computer program for processing historic fire weather data for the National Fire-Danger Rating System.* USDA Forest Serv. Res. Note RM-234, 11 p., illus. Rocky Mountain Forest and Range Exp. Stn. Ft. Collins, Colo.
FIRDAT, a FORTRAN IV program, can compute daily components and indexes, compute and print the absolute, relative, and cumulative frequencies of occurrence, and print a cumulative frequency distribution of each component and index.

1887. Helvey, Roger A.
1967. *Airflow in the San Bernardino-Riverside region Santa Ana of December 10-12, 1963.* 27 p., illus. Univ. Calif. Dep. Meteorol., Los Angeles, Calif.
A possible example of relationship between surface flow and atmospheric structure aloft is presented with the aid of surface hourly streamline maps.

1888. Hull, Melvin K., Clyde A. O'Dell, and Mark J. Schroeder.
1966. *Critical fire weather patterns—their frequency and levels of fire danger.* 43 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The surface and upper-air weather maps for the years 1951-1960 were reviewed to determine the dates on which each type of pattern occurred and the areas that were influenced.

1889. Hull, Melvin K.
1966. *Evaluating winds aloft by a simplified field technique.* U.S. Forest Serv. Res. Note PSW-110, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Explains a technique which can be used at remote places, even at the site of wildfires, that is as accurate as any known single theodolite technique.

1890. Maxwell, Floyd, Morris McCutchan, and Charles F. Roberts.
1974. *Automation of fire weather observations.* Fire

Manage. 35(3):22-25, illus.
The problem in automating the sensing and transmission of weather data is more of an economic than technical consideration.

1891. McCutchan, Morris H., and Robert S. Helfman.
1969. *Synoptic-scale weather disturbances that influence fire climate in Southeast Asia during normally dry periods . . . preliminary report.* 69 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The tropical trough was found to be the synoptic-scale weather disturbance that causes widespread rain and clouds in Southeast Asia.

1892. McCutchan, Mor-is H., and Robert S. Helfman.
1970. *A case study of a wintertime rain situation in Southeast Asia.* Proc. Symp. Tropical Meteorol., Univ. Hawaii, Honolulu, 1970:EIX 1-6.
In this case study, the tropical trough was found to be the synoptic-scale weather disturbance causing the rain and clouds.

1893. McCutchan, Morris H., and Bernadine A. Taylor.
1971. *Synoptic-scale weather disturbances that influence the fire climate in Southeast Asia during the normally dry period. Final report.* 73 p., illus. U.S. Forest Serv., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The five types of synoptic-scale disturbances usually found responsible for rain in Southeast Asia are illustrated by case histories.

1894. McCutchan, Morris H., and Mark J. Schroeder.
1973. *Classification of meteorological patterns in southern California by discriminant analysis.* J. Appl. Meteorol. 12(4):571-577, illus.
Significant differences were found in fire weather and oxidant air pollution exposure on the slope and crest of the San Bernardino Mountains, California, during different meteorological conditions.

1895. McCutchan, Morris H.
1975. *Forest fire meteorology research network.* Proc., WMO Tech. Conf. on Automated Meteorol. Syst. [Washington, D.C. Feb. 19, 1975] WMO Publ. 420, p. 351-360.
An experimental automated network of meteorological stations has been set up in southern California's San Bernardino Mountains to collect data on wind velocity, temperature, and relative humidity for estimating fire danger.

1896. Murray, John R.
1967. *Instrumentation used in the June 14, 1966 Experimental Fire.* Def. At. Spt. Agency DASIAC Spec. Rep. 59:247-255.
Instruments measured and recorded air movements, gas temperatures, flame temperatures, soil temperatures, thermal radiation, heat flux, convection column temperatures, rate of heat output, rate of fuel consumption, upper air movements, and atmospheric pressure.

1897. Murray, John R., and Clive M. Countryman.
1968. *Heat resistant anemometers for fire research.* USDA Forest Serv. Res. Note PSW-181, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A heat-resistant anemometer developed for fire research can be used in normal situations as well as in high temperatures.

1898. Murray, John R., and Clive M. Countryman.
1968. *A portable station for recording fire weather data.* USDA Forest Serv. Res. Note PSW-182, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Portable recording fire weather station has been developed for use in wildland fires and prescribed burns for evaluation of fire weather station sites, and for research studies.

1899. Myrup, Leonard O.
1965. *The structure of thermal convection in the lower atmosphere.* 76 p., illus. Univ. Calif., Dep. Meteorol., Los Angeles, Claif.
Root-mean-square values were calculated for measurements made of the fluctuating temperatures and vertical air speeds over a desert dry lake during the daytime and then related to theoretical and laboratory results.

1900. Orgill, M. M.
1968. *Availability of meteorological data in Southeast Asia.* 50 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes the type of meteorological data available and surveys many but not every possible source of data.

1901. Palmer, Thomas Y.
1970. *Comparison of aspirated and radiation-compensating thermocouples.* Fire Technol. 6(3):224-228, illus.
Compares radiation compensating thermocouples with aspirated thermocouples as part of an on-going experimental program.

1902. Palmer, Thomas Y., and Lee I. Northcutt.
1971. *A high temperature water-cooled anemometer.* Fire Technol. 7(3):201-203, illus.

A water jacket incorporated into the design of the bidirectional anemometer extends instrumental capabilities from 300° C. to 1700° C.

1903. Palmer, Thomas Y.
1971. *Non-seedability of hexadecanol-coated mists.* J. Weather Modif. 3(4):250-252, illus.
Super-cooled water mists coated with the evaporation suppressant hexadecanol cannot be seeded by ordinary methods of dry ice seeding.

1904. Palmer, Thomas Y., and Loyall R. Smith.
1973. *Flame suppressants for propane cold fog seeding.* J. Appl. Meteorol. 12(2):421-422, illus.
Small amounts of promotriflurometհane can be used to reduce or eliminate the fire hazard in propane spray, cloud seeding.

1905. Phillips, Clinton B., and Mark J. Schroeder.
1967. *Sea breeze effects on forest fire behavior in central coastal California.* Calif. Div. For. Fire Control Notes 14, 26 p., illus.
The sea breeze—varying from day to day, or even hour to hour—can have an important influence on the behavior of forest fires burning along the coast or in the intermediate valleys and mountain ranges.

1906. Pirsko, Arthur R.
1959. *Does weather influence urban fires?* Fire Eng. 112(10):938-939, 1009, illus.
Outside humidity and dewpoint affect moisture content of fine fuels inside buildings and hence the frequency of urban fires.

1907. Pirsko, Arthur R.
1960. *1960 fire weather severity in California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 54, 14 p., illus. Berkeley, Calif.
Uses the new ignition and fire load indexes of California fire danger rating to explain the severity of the 1960 fire season and gives a detailed analysis for four areas showing the daily ratings for ignition, burning, and fire load indexes.

1908. Pirsko, Arthur R.
1962. *California's 1961 fire weather brings near-record losses.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 70, 10 p., illus. Berkeley, Calif.
A third consecutive annual drought, an early summer heat wave at lower elevations, and dry autumn winds added up to one of California's worst fire years on record.

1909. Pirsko, Arthur R., Leo M. Sergius, and Carl W. Hickerson.
1965. *Causes and behavior of a tornadic fire whirlwind.* U.S. Forest Serv. Res. Note PSW-61, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The fire whirlwind formed in a post-frontal unstable air mass, cut a mile-long path injuring 4 people, destroying 2 houses, a barn, and 4 automobiles, and wrecking a 100-tree avocado orchard.

1910. Pirsko, Arthur R., and Lisle R. Green.
1967. *Record low fuel moisture follows drought in southern California.* J. For. 65(9):642-643, illus.
Extended drought, particularly from 1959-1961, resulted in extremely low green fuel moisture, and the accumulation of dead twigs and branches on live chaparral shrubs.

1911. Pirsko, Arthur R., and Paul G. Scowcroft.
1969. *Adequate presuppression manning depends on accurate fire-weather observations.* Fire Control Notes 30(1):7-8, illus.
Poor maintenance of fire-weather instruments or sites can lead to low fire danger readings with the resulting error significantly altering strength of initial attack forces dispatched to a given fire.

1912. Ryan, Bill C.
1969. *A vertical perspective of Santa Ana winds in a canyon.* USDA Forest Serv. Res. Paper PSW-52, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Streamline analyses showed that the wind field down the lee side of the canyon dipped significantly, and that opposing wind systems there interacted to allow surface winds to change quickly.

1913. Ryan, Bill C., George R. Ellis, and Donald V. Lust.
1971. *Low-level wind maxima in the 1969 San Mateo and Walker Fires.* USDA Forest Serv. Res. Paper PSW-75, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Concludes that the winds were probably a result of a combination of several mechanisms.

1914. Schroeder, Mark J., and Harry C. Coffin.
1957. *Catalina eddy disrupts weather pattern in the Arroyo Seco.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 131, 9 p. Berkeley, Calif.
Describes the Arroyo Seco fireclimate survey which analyzed the weather pattern under Catalina eddy conditions.

1915. Schroeder, Mark J.
1957. *Fire-weather survey can aid prescribed burning.*

U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 21, 10 p., illus. Berkeley, Calif.
Reports on a short-term fire-weather survey conducted on Iron Mountain prescribed burn, Lassen National Forest in 1956.

1916. Schroeder, Mark J., and Clive M. Countryman.
1960. *Exploratory fireclimate surveys on prescribed burns.* Monthly Weather Rev. 88(4):123-124.
Describes techniques used on four short-term surveys and discusses some results, including an increase in windspeed blowing out of the lee side of the fire, effects of the broadscale weather on local patterns, down-canyon afternoon winds in east-facing canyons, temperature observations and topographic effects on the lee side of a ridge.

1917. Schroeder, Mark J.
1960. *Humidity patterns at middle elevations in the coastal mountains of Southern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 165, 6 p., illus. Berkeley, Calif.
Describes four types of relative humidity patterns observed at a fireclimate station located at 1910 feet on the coast side of the southern California mountains, and relates these patterns to the height of the moist marine layer.

1918. Schroeder, Mark J.
1961. *Down-canyon afternoon winds.* Am. Meteorol. Soc. Bull. 42(8):527-542, illus.
A fireclimate survey in northwestern San Diego County has given some insight into the characteristics of these winds and the relationship of their occurrence to various weather factors which might be used for short-range prediction.

1919. Schroeder, Mark J.
1961. *Topometeorology—the local scale.* Am. Meteorol. Soc. Bull. 42(8):590.
"Topometeorology" is proposed to describe the study of atmospheric processes such as mountain and valley winds, land and sea breezes, or local storms.

1920. Schroeder, Mark J., and others.
1964. *Synoptic weather types associated with critical fire weather.* 492 p., illus. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Berkeley, Calif.
To aid meteorologists the 48 contiguous states were divided into 14 regions, weather data were collected from 89 stations for the period 1951-1960, from which periods of critical fire weather were selected and the synoptic weather types associated with them were determined and described for each of the regions.

1921. Schroeder, Mark J., and Craig C. Chandler.
1966. *Monthly fire behavior patterns.* U.S. Forest Serv. Res. Note PSW-112, 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Presents in map form the probabilities of four classes of fire behavior ranging form 'fire out' to 'critical'.

1922. Schroeder, Mark J., Michael A. Fosberg, Owen P. Cramer, and others.
1967. *Marine air invasion of Pacific Coast: a problem analysis.* Bull. Am. Meteorol. Soc. 48(11):802-808, illus.
Reviews the literature on the main aspects of marine air invasion of the Pacific Coast, in particular, the sea breeze, Pacific Coast monsoon, and airflow over coastal mountains.

1923. Schroeder, Mark J., and Bernadine A. Taylor.
1968. *Inaja Fire—1956, Pine Hills Fire—1967 . . . similar, yet different.* USDA Forest Serv. Res. Note PSW-183, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Compares the fire weather and behavior of two fires, that burned in the same area under similar weather conditions, 11 years apart, yet the first was much more damaging than the second, and attempts to explain why there was such a great difference in controlling the fires.

1924. Schroeder, Mark J.
1969. *Critical fire weather patterns in the conterminous United States.* ESSA Tech. Rep., Weather Bureau BW-8, 31 p., illus. U.S. Dep. Commerce, Silver Spring, Maryland.
The weather types associated with high fire danger in each of 14 regions covering the 48 states are identified and described with high fire danger found around the periphery of high pressure areas.

1925. Schroeder, Mark J., and Charles C. Buck.
1970. *Fire weather . . . a guide for application of meteorological information to forest fire control operations.* U.S. Dep. Agric., Agric. Handb. 360, 229 p., illus.
Describes the components of the atmosphere and the elements of weather that need to be understood because the behavior of wildland fire depends on them.

1926. Scowcroft, Paul G.
1970. *Probability fire weather forecasts . . . show promise in 3-year trial.* USDA Forest Serv. Res. Note PSW-201, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Probability forecasts show promise of being better than either categorical or climatology forecasts.

1927. Show, S. B., and E. I. Kotok.
1925. *Weather conditions and forest fires in California.* U.S. Dep. Agric. Dep. Circ. No. 354, 24 p. Gov. Print. Off. Washington, D.C.
Defines fire weather and concludes that critical fire weather periods are characterized by very low relative humidity and high wind velocity, and that short term forecasts offer a major opportunity for improving systematic fire protection in the pine region of California.

1928. Taylor, Bernadine A.
1974. *Learning fire weather—a self-study course.* USDA TT-89-(5100), 69 p., illus.
This training text is intended to extend the usefulness of *Fire Weather* (USDA Agric. Handb. 360) by offering a self-study course with the Handbook serving as a text.

1929. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn.
1958. *California fire danger rating fire weather station installation and maintenance.* 51 p., illus. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes procedures for selecting fire weather station sites, and for installing and maintaining fire weather equipment.

Fire Chemistry

1930. Broido, A.
1961. *Effect of fire-extinguishing agents on combustion of sucrose.* Science 133(3465):1701-1702, illus.
Although sucrose and cellulose are both carbohydrates of basically similar composition, the very materials which have been found to be most effective in preventing flaming combustion are also effective in causing sugar cubes to support flame.

1931. Broido, A., and S. Martin.
1961. *Effect of potassium bicarbonate on the ignition of cellulose by thermal radiation.* USNRDL-TR-536, Fire Cont. Res. Symp., Fire Res. Abst. and Rev. 3(3):193-201, illus.
$KHCO_3$ treatment of cellulose papers reduced their sensitivity to transient flaming, prevented sustained flaming, increased sensitivity to glowing ignition and produced combustive gases (H_2, CH_2, C_2H_4, and C_2H_6) during pyrolysis.

1931. Broido, A., and F. J. Kilzer.
1963. *A critique of the present state of knowledge of the mechanism of cellulose pyrolysis.* Fire Res. Abstr. and Rev. 5:157-161.
Reviews several divergent theories, raises questions about experimental results obtained prior to the recent recognition of the importance of trace impurities, and indicates the need for sufficient detail in the reaction mechanism to permit a better prediction of the action of fire extinguishing and flame retarding chemicals.

1933. Broido, A., and Maxine A. Nelson.
1964. *Ash content—its effect on combustion of corn plants.* Science 146(3644):652-653.
Two corn plant samples—one cut in the fall while green, the other following weathering over the winter—exhibited the same drastic combustion differences as do pure and treated cellulose with the increased susceptibility to flaming combustion of the spring harvested sample attributable to its decreased ash content, and not directly to its moisture content.

1934. Broido, A., Y. Houminer, and S. Patai.
1966. *Pyrolytic reactions of carbohydrates. Part I. Mutarotation of molten d-glucose.* J. Chem. Soc. 1966(B):411-414.
Reports that the process of mutarotation quickly speeds up as soon as the bulk of the material melted.

1935. Broido, A.
1966. *Thermogravimetric and differential thermal analysis of potassium bicarbonate contaminated cellulose.* Pyrodynamics 4(3):243-251, illus.
Found that as little as .15 percent inorganic contamination can affect the pyrolysis reactions undergone by cellulose and that the addition of 1.5 percent $KHCO_3$ essentially eliminated the flame-producing reactions in favor of those leading to growing combustion.

1936. Broido, A.
1968. *On the Chatterjee method of obtaining kinetic parameters from thermogravimetric traces.* J. Polymer Sci., Part B. 6:349-351.
Points out flaws in a technique for determining the order of a pyrolysis reaction from two thermogravimetric analysis curves obtained under similar conditions with two different initial weights of sample.

1937. Broido, A.
1969. *A simple sensitive graphical method of treating thermogravimetric analysis data.* J. Polymer Sci. A-2, 7(10):1761-1773, illus.
A linear plot of thermogravimetric analysis data provides an extremely sensitive method of detecting even small deviations in a simple pyrolysis action and of separating component reactions in a more complicated pyrolysis process.

1938. Broido, A., and M. Weinstein.
1970. *Thermogravimetric analysis of ammonia-swelled cellulose.* Combust. Sci. and Technol. 1(4):279-285, illus.
Cellulose decrystallized by swelling in liquid ammonia produces a simpler thermogravimetric analysis curve than obtained from ordinary cellulose—presumably because of a decrease in the intermolecular char-forming reactions.

1939. Broido, A., and M. Weinstein.
1972. *Low temperature isothermal pyrolysis of cellulose.* In *Thermal analysis.* Vol. 3, p. 285-296, illus. Hans G. Wiedemann, ed. Birkhauser Verlag, Basel.
Illustrates the utility of looking at minor weight deviations, too large to be random experimental error, in a 1000-hour isothermal pyrolysis experiment on high purity cellulose paper at 226° C.

1940. Broido, A.
1973. *Flammable—whatever that means.* Chem. Technol. 3(1):14-17, illus.
Researchers have not yet come up with a meaningful test of combustibility, nor is there a widely accepted definition of the term.

1941. Broido, A., A. C. Javier-son, A. C. Ouano, and Edward M. Barrall, II.
1973. *Molecular weight decrease in the early pyrolysis of crystalline and amorphous cellulose.* J. Appl. Polymer Sci. 17:3627-3635, illus.
Pyrolysis studies on ordinary and decrystallized cellulose support the suggestion that initial rupture of the cellulose molecule on heating occurs at strain points at the crystalline-amorphous interfaces.

1942. Broido, A., and F. A. Williams.
1973. *Use of asymptotic analysis of the large activation-energy limit to compare graphical methods of treating thermogravimetry data.* Thermochimica Acta 6:245-253, illus.
The second approximate method showed exceedingly accurate reduction of TGA data, and can be justified on the basis of an asymptotic expansion with a nondimensional activation energy as the large parameter.

1943. Broido, A., and Maxine A. Nelson.
1975. *Char yield on pyrolysis of cellulose.* Combust. and Flame 24:263-268.
Whether the pyrolysis of cellulose is conducted in an inert medium or in air, partial pyrolysis at a lower temperature increases the char yield obtained after 1 hour at 370° C.

1944. Broido, A., M. Evett, and Craig C. Hodges.
1975. *Yield of 1,6-anhydro-3,4-dideoxy-β-D-glycero-hex-3-enopyranos-2-ulose(levoglucosenone) on the acid-catalyzed pyrolysis of cellulose and 1,6-anhydro-β-D-gluco-pyranose (levoglucosan).* Carbohydr. Res. 44:267-274.
The principal mechanism of levoglucosenone formation on cellulose pyrolysis is not through levoglucosan (and levoglucosan itself is not a primary product) but must involve a volatile and as yet unidentified precursor.

1945. Byram, G. M., W. L. Fons, F. M. Sauer, and R. K. Arnold.
1952. *Thermal properties of forest fuels.* 34 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Discusses heat of decomposition of wood and specific heat of a wood-water system as related to combustion.

1946. Fons, W. L.
1961. *Rate of combustion from free surfaces of liquid hydrocarbons.* Combust. and Flame 5(3):283-287, illus.
Presents the results of a series of laboratory experiments in which liquid hydrocarbons were burned in circular pans to learn the influence of diameter of the fuel surface on the rate of combustion.

1947. Halpern, Yuval, Yoram Houminer, and S. Patai.
1967. *Quantitative determination of silyl derivatives of glucose by gas-liquid chromatography with inert internal standards.* Analyst 92:714-716, illus.
Trimethylsilyl derivatives of α- and β-D-glucose were determined quantitatively, with an internal standard, such as terphenyl or triphenylethylene.

1948. Halpern, Yuval, and S. Patai.
1969. *Pyrolytic reactions of carbohydrates. Part V. Isothermal decomposition of cellulose in vacuo.* Israel J. Chem. 7:673-683.
Proposes a general scheme for the process in analyzing the decomposition products appearing in different fractions, and in determining the product ratios at different stages of the reaction.

1949. Halpern, Yuval, and S. Patai.
1969. *Pyrolytic reactions of carbohydrates. Part VI. Isothermal decomposition of cellulose in vacuo, in the presence of additives.* Israel J. Chem. 7:685-690.
The isothermal decomposition of cellulose at 250° and 275° C. was investigated in the presence of neutral, acidic, and basic additives.

1950. Halpern, Yuval, and S. Patai.
1969. *Pyrolytic reactions of carbohydrates. Part VII. Simultaneous DTA-TGA study of the thermal*

decomposition of cellulose in vacuo. Israel J. Chem. 7:691-696, illus.
Finds that the overall process was endothermic in untreated cellulose and in the presence of acidic catalyists, but changed into an exothermal reaction in the presence of strong bases.

1951. Halpern, Yuval, Richard Riffer, and A. Broido.
1972. *Levoglucosenone (1,6-anhydro-3,4-dideoxy-Δ^3-β-D-pyranosen-2-one). A major product of the acid-catalyzed pyrolysis of cellulose and related carbohydrates.* J. Org. Chem. 38(2):204-209, illus.
In retardants, a new compound replaces levoglucosan as the major constituent of a still significant tar fraction.

1952. Houminer, Yoram, and S. Patai.
1967. *Thermal decomposition of D-glucose labelled with ^{14}C at various positions.* Tetrahedron Letters 14:1297-1300. London, Pergamon Press Ltd.
Reports on the pathways through which the carbon skeleton of glucose molecule is cleaved during its thermal decomposition, using glucose labeled with ^{14}C either uniformly or at the positions 1, 2, or 6.

1953. Houminer, Yoram, and Meir Weinstein.
1968. *A simple technique for collecting $^{14}CO_2$ under reduced pressure for liquid scintillation counting.* Int. J. Appl. Radiat. and Isotopes 19:663-664, illus.
Describes a method that should be valuable in a variety of thermal decomposition reactions in which volatile gases, such as methanex and formaldehyde, are liberated.

1954. Houminer, Yoran, and S. Patai.
1969. *Pyrolytic reactions of carbohydrates. Part II. Thermal decomposition of D-glucose.* Israel J. Chem. 7:513-524, illus.
Mechanisms for dehydration and fragmentation processes are discussed.

1955. Houminer, Yoran, and S. Patai.
1969. *Pyrolytic reactions of carbohydrates. Part III. Thermal decomposition of D-glucose.* Israel J. Chem. *of additives.* Israel J. Chem. 7:525-534.
Different classes of additives were found to catalyse or inhibit different steps in the overall decomposition process.

1956. Houminer, Yoran, and S. Patai.
1969. *Pyrolytic reactions of carbohydrates. Part IV. Anhydro-sugar formation and transglycosylation in the thermal reactions of various glucose derivatives.* Israel J. Chem. 7:535-546.
Reports that the cleavage of glucosidic linkages in general involves both transglycosylation and hydrolysis.

1957. Houminer, Yoran, S. Hoz, and S. Patai.
1969. *Pyrolytic reactions of carbohydrates. Part VIII. The decomposition of D-glucose labelled with ^{14}C at different positions, catalyzed by various additives.* Israel J. Chem. 7:821-825.
The aqueous and tarry fractions are analyzed and the amount and radioactivity of the evolved carbon dioxide and monoxide are determined.

1958. Kilzer, F. J., and A. Broido.
1965. *Speculations on the nature of cellulose pyrolysis.* Pyrodynamics 2(2-3):151-163.
Pure cellulose appears to decompose by two competitive endothermic processes: an unzipping reaction producing, 1,4-anyhdro-α-D glucopyranose which rearranges to give levoglucosan; and a dehydration followed by an exothermic process which results in CO_2, CO, H_2O, and char.

1959. McCarter, R. J., and A. Broido.
1967. *A calorimeter for determining radiation and convection in small-scale combustions.* Pyrodynamics 4(2):191-203, illus.
A 'bench-top' calorimeter was built and successfully used to measure a variety of solid and liquid fuels and both glowing and flaming modes of combustion.

1960. Ouano, A. C., A. Broido, E. M. Barral, and A. J. Son.
1971. *Gel permeation chromatography. VI. Molecular weight averages and molecular weight distribution of cellulose nitrate.* Polymer Reprints 12(2):859-864, illus.
For estimating cellulose molecular weight averages from the GPC retention volume distribution and polystyrene calibration curves, calculations based on hydrodynamic values rather than on extended chain length give values in good agreement with viscometric results.

1961. Patai, S., Yuval Halpern, L. Esterman, and Meir Weinstein.
1968. *An apparatus for simultaneous DTA and TGA.* Israel J. Chem. 6:445-449, illus.
The apparatus, based on a Cann electrobalance, is comparatively inexpensive and enables reactions to be studied *in vacuo*, or in any chosen atmosphere.

1962. Patai, S., and Yuval Halpern.
1970. *Pyrolytic reaction of carbohydrates. Part IX. The effect of additives on the thermal behavior of cellulose samples of different crystallinity.* Israel J. Chem. 8:655-662.
The thermal decomposition of four different cellulose samples was studied at 250° and weight loss, total

organic volatiles, levoglucosan, water, acids, average degree of polymerization, and crystallinity index were determined.

1963. Riffer, Richard, and A. Broido.
1974. *Asymmetric distribution in the biosynthesis of cotton cellulose-(U-^{14}C).* J. Exp. Bot. 25(84):216-218.
Autoradiographs of mature cotton balls into which radioglucose had been introduced earlier showed a marked asymmetry in distribution of the label.

1964. Stein, Andrew M., and Brian W. Bauske.
1972. *Computer technique for simulating the combustion of cellulose and other fuels.* USDA Forest Serv. Res. Note PSW-266, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a computer technique in which the products of combustion are used as input for a convection model that simulates real fires.

1965. Weinstein, Meir, and A. Broido.
1970. *Pyrolysis—crystallinity relationships in cellulose.* Combust. Sci. and Technol. 1(4):287-292, illus.
Swelling cellulose in liquid ammonia can eliminate the crystalline X-ray diffraction pattern, but heating restores a considerable degree of order.

FOREST ENVIRONMENT (OTHER RESOURCE MANAGEMENT)

Watershed Management

1966. Ackermann, W. C., E. A. Coleman, and H. O. Ogrosky.
1955. *From ocean to sky to land to ocean. Water.* U.S. Dep. Agric. Yearb. 1955:41-48, illus.
Describes the hydrologic cycle and points out where man can exert influences over water.

1967. Amidon, R. E.
1947. *Discussion of model study of Brown Canyon debris barrier.* Am. Soc. Civ. Eng. Trans. 112:1015-1016.

1968. Anderson, Henry W.
1949. *Does burning increase surface runoff?* J. For. 47(1):54-57.
Cover type and long term effects of repeated burning should be considered to properly evaluate the economics of burning and its influence on flood and erosion problems.

1969. Anderson, Henry W.
1949. *Flood frequencies and sedimentation from forest watersheds.* Am. Geophys. Union Trans. 30(4):567-584.
A multivariable approach was used to develop a hydrologic basis for evaluating flood control in southern California.

1970. Anderson, Henry W., and H. K. Trobitz.
1949. *Influence of some watershed variables on a major flood.* J. For. 47(5):347-356.
Peak discharges and sediment deposition from watersheds during a major flood were found to be quantitatively related to forest cover density and other watershed characteristics.

1971. Anderson, Henry W.
1950. *Discussion of flood frequencies and sedimentation from forest watersheds.* Am. Geophys. Union Trans. 30(4):567-584. Also, Am. Geophys. Trans. 31(4):621-623.
Discusses peak discharges and sedimentation from watersheds as they relate to storm and watershed variables in studies of flood causes.

1972. Anderson, Henry W.
1951. *Physical characteristics of soils related to erosion.* J. Soil and Water Conserv. 6(3):129-133.
Soil erodibility is qualitatively dependent on the parent material and quantitatively dependent on the cover density and physical characteristics of the surface soils in each geologic type.

1973. Anderson, Henry. W.
1952. *How will you have your water?* J. For. 50(2):135.
Discusses implications of forest management practices on water quality and use.

1974. Anderson, Henry W.
1954. *Suspended sediment discharge as related to streamflow, topography, soil, and land use.* Am. Geophys. Union Trans. 35(2):268-281.
Describes an analytical method for estimating the erosion potential of land areas, and shows how erosion rates differ from potential rates under various kinds of land use.

1975. Anderson, Henry W.
1955. *Detecting hydrologic effects of changes in watershed conditions by double-mass analysis.* Am. Geophys. Union Trans. 36:119-125, illus.
Shows one way of detecting the effects of wildfires on sedimentation and flood peaks, and illustrates how to take into account such effects when estimating long-term sedimentation and flood frequency from the short-term records usually available.

1976. Anderson, Henry W.
1956. *Forest-cover effects on snowpack accumulation and melt, Central Sierra Snow Laboratory.* Am. Geophys. Union Trans. 37(3):307-312.
The study is interpreted in terms of timbercutting patterns that would result in maximum snow accumulation and minimum melt rate.

1977. Anderson, Henry W.
1956. *Relating sediment yield to watershed variables.* Am. Geophys. Union Trans. 37(3):335.
Discusses the uses of multiple regression analysis as a means of relating sediment yield to such variables as watershed conditions and the nature of storms and streamflow.

1978. Anderson, Henry W.
1957. *Forest-cover effects on snowpack accumulation and melt, Central Sierra Snow Laboratory.* Am. Geophys. Union Trans. 38(1):116.
Discusses the status of Church's "honeycomb" forest and Anderson's "wall-and-step" forest as guides to logging for snowpack management.

1979. Anderson, Henry W.
1957. *Operation Wet-Blanket gets underway.* Am. Geophys. Union Trans. 38(3):414.
Outlines the snowpack management studies now being conducted in cooperation with the California Department of Water Resources.

1980. Anderson, Henry W.
1957. *Relating sediment yield to watershed variables.* Am. Geophys. Union Trans. 38(6):921-924.
Discusses uses of multiple regression analysis as a means of relating sediment yield to such variables as watershed conditons and the nature of storms and streamflow.

1981. Anderson, Henry W.
1957. *Snow on forested slopes.* West. Snow Conf. Proc. 1957:19-23.
Snow accumulation and melt at 31 Central Sierra Snow Laboratory snow courses are related to terrain, solar energy, and forest variables.

1982. Anderson, Henry W.
1958. *Forest effects on floods in Northwest.* Am. Geophys. Union Trans. 39(3):504.
Effects of forest conditions on floods for three areas of the Pacific Northwest were evaluated using multiple regression, covariance, and double-mass analysis.

1983. Anderson, Henry W.
1958. *Forest shade related to snow accumulation.* West. Snow Conf. Proc. 1958:21-31.
A computer program, which tested forest conditions as they affect snow accumulation, worked best when it indexed the separate effects of forests on solar radiation received at the snow surface, back radiation from the trees, and the interchange of energy between forests, clouds, and sky.

1984. Anderson, Henry W.
1958. *Progress in snow management research in California.* West. Snow Conf. Proc. 1958:12-21.
Plans, methods, and some results from 18 studies now underway in California are summarized.

1985. Anderson, Henry W.
1958. *Rain-snow flood sources meteorologically defined.* Bull. Am. Meteorol. Soc. 39(3):174-175.
Flood peak discharges of 54 watersheds of the Willamette Basin, Oregon, in 43 storms were related to five meteorological and four watershed variables.

1986. Anderson, Henry W., and Robert L. Hobba.
1959. *Forests and floods in the northwestern United States.* Int. Union of Geodesy and Geophys. Symp. on Woodl. and Water. Proc. 1959:30-39.
Evaluates effects of timber cutting and burning on flood peak discharges in rain-on-snow and snowmelt floods using methods of multiple regression, covariance, and double-mass analysis.

1987. Anderson, Henry W., and Clark H. Gleason.
1959. *Logging effects on snow, soil moisture, and water losses.* 27th Annu. West. Snow Conf. Proc. 1959:57-65.
Reports first-year studies of water yield in the Sierra Nevada as affected by 3 types of logging, and of snow accumulation as affected by forests, natural forest openings, and three kinds of slash disposal.

1988. Anderson, Henry W., Raymond M. Rice, and Allan J. West.
1959. *Snow in forest openings and forest stands.* Soc. Am. For. Proc. 1958:46-50, illus.
Snow measurements of 57 courses in 1957-58 are interpreted to give choices of size, shape, and orientation of forest openings for increasing snow accumulation and delaying melt.

1989. Anderson, Henry W., G. B. Coleman, and P. J. Zinke.
1959. *Summer slides and winter scour—dry-wet erosion in southern California mountains.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 36, 12 p., illus. Berkeley, Calif.
Summarizes the results of 5 years' study of the sources and the process of soil, rock, and organic debris movement down slopes of the San Gabriel Mountains.

1990. Anderson, Henry W.
1959. *Water yield control through management in snow pack watersheds.* First Intersociety Conf. on Irrig. and Drain. Proc. 1959:13-18.
Discusses approaches to water yield improvement, describes research begun in 1957 toward such improvement, and gives early results from some studies.

1991. Anderson, Henry W., and Clark H. Gleason.
1960. *Effects of logging and brush removal on snow water runoff.* Int. Assoc. Sci. Hydrol. Publ. 51:478-489.
Summarizes the effects of various forest harvesting methods, slash disposal and brush clearing on snow accumulation and soil moisture losses, and estimates the effects on water yield.

1992. Anderson, Henry W.
1960. *Proposed program for watershed management research in the lower conifer zone of California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 46, 21 p., illus. Berkeley, Calif.
Analyzes problems and present state of knowledge affecting watershed management in California's commercial timber zone where rainfall is heavy and snowmelt rapid.

1993. Anderson, Henry W.
1960. *Prospects for affecting the quantity and timing of water yield through snowpack management in California.* West. Snow Conf. Proc. 1960:44-50.
Research results are interpreted so as to contrast snow accumulation and water yield under clearcutting, strip cutting, block cutting, selection cutting, and a special "ideal forest" cutting.

1994. Anderson, Henry W.
1960. *Research in management of snowpack watersheds for water yield control.* J. For. 58:282-284.
Outlines the California Cooperative Snow Management Research Program and reports some of the first results from the work.

1995. Anderson, Henry W.
1960. *Water management forestry—a model approach.* Proc. Fifth World For. Congr. Vol. 3, Seattle, Wash., 1960:1734-1738.
Proposes that terms describing forest conditions as related to water yield and to flood and sediment control can be used in designing forests which will closely meet management standards.

1996. Anderson, Henry W.
1962. *Current research in sedimentation and erosion in California wildlands.* Int. Assoc. Sci. Hydrol. Publ. 59:173-182.
Summarizes results of eight studies of sediment sources, sediment processes and the effects of logging, fires, and post-fire treatments on erosion and sediment discharge from California wildland watersheds.

1997. Anderson, Henry W., and L. G. Richards.
1962. *Fourth progress report, 1960-61, Cooperative Snow Management Research.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. p. 141-204.
Contains yearly progress reports and separate technical studies aimed at improving California's water yield through management of land in the snowpack zone.

1998. Anderson, Henry W.
1962. *A model for evaluating wildland management for flood prevention.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 69, 19 p., illus. Berkeley, Calif.
Outlines some of the processes of flood hydrology and proposes models and analyses to evaluate flood causes, flood source and flood prevention.

1999. Anderson, Henry W., Walt Hopkins, and Robert E. Nelson.
1962. *A program for watershed management research in Hawaii wildlands.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 72, 15 p., illus. Berkeley, Calif.
Suggests a four-step research program: (a) inventories of vegetation, soils, physiographic and climatic sites, and hydrologic and meteorological conditions, (b) studies of forest hydrology, forest meteorology, and plant-soil-water relations, (c) plot and small-scale tests of land management practices, and (d) pilot testing of selected practices on calibrated watersheds.

2000. Anderson, Henry W., Franklin R. Adams, Allan J. West, and Robert R. Ziemer.
1963. *Evaporative loss from soil, native vegetation, and snow as affected by hexadecanol.* I.A.S.H. Comm. for Evaporation Publ. 62, p. 7-12.
Marked reductions in evaporation from snow occurred under certain topographic and cover conditions when hexadecanol emulsion was applied to the snow surface.

2001. Anderson, Henry W.
1963. *Managing California's snow zone lands for water.* U.S. Forest Serv. Res. Paper PSW-6, 28 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The hydrology of California's snow zone is summarized and broad sources of water yield, variability, and distribution are briefly reviewed.

2002. Anderson, Henry W., and James R. Wallis.
1963. *Sediment sources and causes, Pacific Coast basins in Oregon and California.* Proc. Second Interagency Conf. Sedimentation Proc. 1963:22-23.
Discusses differences between associated variables as they appear between units of coastal watersheds.

2003. Anderson, Henry W., Philip M. McDonald, and Lloyd W. Gay.
1963. *Use of radioactive sources in measuring characteristics of snowpacks.* U.S. Forest Serv. Res. Note PSW-11, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Commercially available gamma and neutron probes were tested for their ability to measure snow density, ice lenses, and the thermal quality of individual layers in the snowpack.

2004. Anderson, Henry W.
1964. *Some California hydrologic problems and solutions. Hydrology Study Tour, XIII General Assembly I.U.G.G.* Bull. Int. Assoc. Sci. Hydrol. IX Année, No. 2, p. 5-18.
Representative hydraulic and hydrologic features in central and southern California as described by some 35 technicians of the major State, private and Federal agencies are summarized.

2005. Anderson, Henry W., and James R. Wallis.
1965. *Some interpretations of sediment sources and causes, Pacific Coast Basins in Oregon and California.* U.S. Dep. Agric. Misc. Publ. 970, p. 22-30.
Discusses variance between sediment production and associated variables as it appears between manageable units of watersheds.

2006. Anderson, Henry W.
1966. *Integrating snow zone management with basin management.* In *Water Research.* Allen V. Kneese and Stephen C. Smith, ed., p. 355-373. John Hopkins Press, Baltimore, Md.
Further studies are suggested to aid in basin management.

2007. Anderson, Henry W., Paul D. Duffy, and Teruo Yamamoto.
1966. *Rainfall and streamflow from small tree-covered and fern-covered, and burned watersheds in Hawaii.* U.S. Forest Serv. Res. Paper PSW-34, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Streamflow of two 30-acre watersheds near Honolulu was studied, using principal components regression analysis.

2008. Anderson, Henry W., and Allan J. West.
1966. *Snow accumulation and melt in relation to terrain in wet and dry years.* Proc. 33rd Annu. West. Snow Conf. 1965:73-82, illus.
Analyzes snow data from 163 snow courses in the central Sierra Nevada of California, using factor analysis and principal component regression analysis.

2009. Anderson, Henry W.
1966. *Summary of forests and soil stabilization session.* Proc. Int. Symp. Forest Hydrol., Penn. State Univ. 1965:699-700.
Special problems on sedimentation from forest watersheds are discussed in the light of problems currently being researched.

2010. Anderson, Henry W.
1966. *Watershed modeling approach to evaluation of the hydrology potential of unit areas.* Proc. Int. Symp. Forest Hydrol., Penn. State Univ. 1965:735-746.
Describes a model relating sediment discharge from 46 watersheds in northern California to watershed variables, and a model relating snow accumulation at 163 snow courses to variables of terrain, including forest variables.

2011. Anderson, Henry W.
1967. *Abstracted bibliography of erosion of cohesive materials.* Am. Soc. Civ. Eng. Proc., J. Hydraul. Div. 93(HY1):117-124.
This contributes 7 additional publications to the 67 abstracted in the Am. Soc. Civ. Eng., Hydraul. Div. HY2:243-290, March 1966.

2012. Anderson, Henry W.
1967. *Erosion and sedimentation.* Trans. Am. Geophys. Union 48(2):697-700.
Summarizes progress in erosion and sedimentation research in the United States during the five years 1962-1966.

2013. Anderson, Henry W.
1967. *General report. Symposium subject: New ideas and scientific methods in stochastic (statistical) hydrology.* Int. Hydrol. Symp. Proc. 1967(2):322-335.
Summarizes, critically reviews, and expands on contents of eight papers on stochastic (statistical) hydrology, prepared by various authors.

2014. Anderson, Henry W.
1967. *Snow accumulation as related to meteorological, topographic, and forest variables in central Sierra Nevada of California.* Int. Assoc. Sci. Hydrol. Publ. 78:215-224, illus.

Snow accumulation at individual points in forest and openings in forest was studied by selecting 16 periods in winter 1957-58.

2015. Anderson, Henry W., and Theodor B. Yerke.
1968. *Computer documentation and retrieval of hydrologic information for small research groups or individuals.* Int. Assoc. Sci. Hydrol. Publ. 81(2):555-560.
The U.S. Forest Service has developed a personal documentation system (FAMULUS) which "automates" a personal file and provides updating, editing, vocabulary-building, and searching capabilities.

2016. Anderson, Henry W.
1969. *Snowpack management.* In *Snow.* Oregon State Univ. Water Resour. Inst. Seminar WR 011-69:27-40, illus.
Summarizes results of research in California and Colorado on accumulation of snow, snowmelt, and disposition of snowmelt water as affected by forest cutting patterns, clearing of brushfields, and mechanical control of snow drifting.

2017. Anderson, Henry W.
1970. *Principal components analysis of watershed variables affecting suspended sediment discharge after a major flood.* Int. Assoc. Sci. Hydrol. Publ. 96:404-416.
Evaluates storm and watershed conditions which were responsible for sediment increases following two major floods in California.

2018. Anderson, Henry W.
1970. *Storage and delivery of rainfall and snowmelt water as related to forest environments.* Proc. Third Forest Microclimate Symp., Seebe, Alberta, Can. For. Serv., Calgary, Alberta 1969:51-67.
Forest-water interactions affecting three groups of hydrologic processes are discussed: those affecting fog drip, falling rain, snow accumulation, and snowmelt, those affecting storage and delivery of water, and those affecting energy transfers.

2019. Anderson, Henry W.
1971. *Relative contributions of sediment from source areas and transport processes.* Proc. Symp. Forest Land Use and Stream Environ., Oreg. State Univ., Corvallis, 1971:55-63, illus.
Reports new findings, offers a re-analysis of older studies, and summarizes pertinent results in the literature.

2020. Anderson, Henry W.
1972. *Forest and meteorological influences on snow and snowmelt water and their management.* Proc. Jt. FAO/USSR Int. Symp. For. Influences and Watershed Manage., Moscow, USSR 1970:41-54.
Reports quantitative effects for a few specific techniques in specific areas, and discusses those that may be used to meet objectives of water supply, flood and erosion prevention, and water quality control.

2021. Anderson, Henry W.
1972. *Major floods, poor land use delay return of sedimentation to normal rates.* USDA Forest Serv. Res. Note PSW-268, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Recovery from flood-accelerated sedimentation influences both estimates of long-term average sedimentation and short-term monitoring of sedimentation changes.

2022. Anderson, Henry W.
1972. *Water yield as an index of lee and windward topographic effects on precipitation.* In *Distribution of precipitation in mountainous areas.* Vol. II, WMO/OMM No. 326, p. 346-358, illus. Geneva, Switzerland: World Meteorol. Organ.
Introduces and evaluates new topographic variables of rise and spillover into evaluation of precipitation in the lee of mountain barriers and an indicated "breakthrough" in use of snow accumulation in estimating total winter precipitation by elevation zones.

2023. Anderson, Henry W.
1974. *Sediment deposition in reservoirs associated with rural roads, forest fires, and catchment attributes.* IAHS-AISH Publ. 113:87-89.
Variables contributing most to explained variance in sediment deposition were, in decreasing order, snow, geology, streamflow, forest fires, and reservoirs.

2024. Anderson, Henry W.
1975. *The hydrologic potential of unit areas: a basis for managing water resources.* Proc. Second World Congr., Int. Water Resour. Assoc., New Delhi, India, Dec. 1975, Vol. IV, p. 61-69.
Data from 93 watersheds in northern California, for the period 1881-1971, were used to relate four streamflow characteristics to 29 watershed variables.

2025. Anderson, Henry W.
1975. *Relation of reservoir sedimentation to catchment attributes, landslide potential, geologic faults, and predicted density.* In *Proc. Symp. The Hydrological Characteristics of River Basins, Tokyo, Japan.* Dec. 1-8, 1975:629-638, illus. IAHS-AISH Publ. 117.
Regression results permit predictions of sediment deposition from unmeasured watersheds and estimation of the effects of deposition on changes in land use.

2026. Anderson, Henry W.
1975. *Sedimentation and turbidity hazards in wildlands.* In *Watershed Management,* ASCE 1975, Proc. Watershed Manage. Symp., Div. of Irrig. and Drain., Am. Soc. Civ. Eng., Logan, Utah, August 11-13, 1975, p. 347-376.
How sedimentation and streamflow turbidity hazards can be judged is illustrated by citing results of current and past studies.

2027. Andre, Johnnie E., and Henry W. Anderson.
1961. *Variation of soil erodibility with geology, geographic zone, elevation, and vegetation type in northern California wildlands.* J. Geophys. Res. 66(10):3351-3358.
Soil samples from 158 places were analyzed for physical characteristics which index erodibility of the soil.

2028. Andrews, L. A.
1957. *Inexpensive maximum water stage recorder.* Eng. News-Record. June 13, 1957:86, illus.
Describes an easily built instrument that can be used to record peak flow where expensive gaging stations are not justified.

2029. Andrews, L. A.
1958. *Added pen takes guess out of flow gage.* Eng. News-Record. June 19, 1958:125.
Describes an attachment for indicating pen reversals on FW-1 water-level records to aid in correct interpretation of streamflow records.

2030. Bailey, Robert G., and Raymond M. Rice.
1969. *Soil slippage: an indicator of slope instability on chaparral watersheds of southern California.* Prof. Geogr. 21(3):172-177, illus.
Reports a study of soil slippage on 29 brush and grass sites on the San Dimas Experimental Forest, near Glendora, California.

2031. Barnes, F. F., C. J. Kraebel, and R. S. LaMotte.
1939. *Effect of accelerated erosion on silting in Morena Reservoir, San Diego County, Calif.* U.S. Dep. Agric. Tech. Bull. No. 639, 22 p. U.S. Gov. Print. Off., Washington, D.C.
Overgrazing and repeated burning for the production of forage were the chief causes of accelerated erosion which had displaced over 10 percent of the reservoir storage capacity by 1935.

2032. Bentley, Jay R.
1961. *Fitting brush conversion to San Gabriel watersheds.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 61, 8 p., illus. Berkeley, Calif.
A soil survey of the San Dimas Experimental Forest showed that steep slopes or shallow soils, or both, occupy 90 percent of the area and greatly limit the opportunities for conversion of native brush to a different plant cover.

2033. Bentley, Jay R., Verdie E. White, and Lisle R. Green.
1961. *Helicopter sowing of burned watersheds on the San Dimas Experimental Forest, 1960.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 62, 7 p., illus. Berkeley, Calif.
Describes flight operations and seed handling methods used to sow grass seed on 13,496 acres and gives costs, exclusive of seed and seed mixing.

2034. Bodman, G. B., and E. A. Colman.
1944. *Moisture and energy conditions during downward entry of water into soils.* Soil Sci. Soc. Am. Proc. 8:116-122.
Experiments show that changes in infiltration rate is determined by the soil moisture distribution, moisture-potential conditions and permeability.

2035. Boersma, L. L., D. Kirkham, D. Norum, R. Ziemer, and others.
1971. *Soil moisture.* Trans. Am. Geophys. Union 52(6):IUGG279-IUGG285.
This review on the progress of research on the physics of soil moisture includes an extensive bibliography.

2036. Bowden, Kenneth L., and James R. Wallis.
1964. *Effect of stream ordering technique upon Horton's laws of drainage composition.* Geol. Soc. of Am. Bull. 75(8):767-774.
Discusses Horton's laws, the modifications made upon them by Strahler and others, and attempts to clarify concepts which often cause confusion.

2037. Brock, Richard R., and Jay S. Krammes.
1964. *A study of trapazoidal flume models at San Dimas.* U.S. Forest Serv. Res. Note PSW-50, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Presents rating curves applicable to small and large flume installations in which approach velocity permits a hydraulic control to exist.

2038. Buck, Charles C., Wallace L. Fons, and Clive M. Countryman.
1948. *Average fire damage from increased run-off and erosion on the southern California National Forests.*

25 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes and reports average damage figures from individual surveys of Angeles, Cleveland, Los Padres and San Bernardino National Forests.

2039. Buck, Charles C., Wallace L. Fons, and Clive M. Countryman.
1948. *Fire damage from increased run-off and erosion, Angeles National Forest.* 116 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Extensively surveys damage to forest watersheds caused by fire and subsequent increases in flooding and erosion.

2040. Buck, Charles C., Wallace L. Fons, and Clive M. Countryman.
1948. *Fire damage from increased run-off and erosion, Cleveland National Forest.* 63 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
See item 2039 above.

2041. Buck, Charles C., Wallace L. Fons, and Clive M. Countryman.
1948. *Fire damage from increased run-off and erosion, Los Padres National Forest.* 107 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
See item 2039 above.

2042. Buck, Charles C., Wallace L. Fons, and Clive M. Countryman.
1948. *Fire damage from increased run-off and erosion, San Bernardino National Forest.* 63 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
See item 2039 above.

2043. Colman, E. A.
1943. *Report of the American Geophysical Union Committee on transpiration and evaporation, 1942-43.* Am. Geophys. Union Trans. 1943:401-402.
Discusses work being conducted on the San Dimas Experimental Forest to measure evapotranspiration water losses under natural watershed conditions and in lysimeters.

2044. Colman, E. A.
1944. *The dependence of field capacity upon the depth of wetting of field soils.* Soil Sci. 58(1):43-50.
Studies showed that these soils must be wetted 12 to 30 inches deep before the surface layer will have attained a moisture content as high as its field capacity.

2045. Colman, E. A., and G. B. Bodman.
1944. *Moisture and energy conditions during downward entry of water into moist and layered soils.* Soil Sci. Soc. Am. Proc. 9:3-11.
Demonstrates that the infiltration principles noted in initially dry soil columns of uniform texture are applicable in interpreting the infiltration process in dry nonuniform soil columns and moist columns of uniform textures.

2046. Colman, E. A., and E. L. Hamilton.
1944. *The San Dimas water-stage transmitter.* Civ. Eng. 14(6):257-258.
A float operated water level transmitter was designed for the San Dimas lysimeters to make synchronized measurements of the rate of water flow.

2047. Colman, E. A.
1946. *A laboratory study of lysimeter drainage under controlled soil moisture tension.* Soil Sci. 62(5):365-382.
Results showed that it was possible to control the seepage rate and the drained moisture content of a deep soil column by controlling the moisture tension maintained at the base of the soil.

2048. Colman, E. A.
1946. *The place of electrical soil-moisture meters in hydrologic research.* Am. Geophys. Union Trans. 1946:847-853.
A portable meter can be used to control the time and amount of irrigation on crop land, and to measure accretions and losses of soil moisture as well as the direction and rate of soil-water movement and the freezing and melting conditions of water in soil and snow.

2049. Colman, E. A., W. B. Hanawalt, and C. R. Burck.
1946. *Some improvements in tensiometer design.* Am. Soc. Agron. J. 38(5):455-458.
Describes a type of tensiometer which reduces the difficulty encountered in inserting and removing the porous cup, reduces fluctuations in manometer readings, and eliminates air entrapment within the cup.

2050. Colman, E. A.
1947. *A laboratory procedure for determining the field capacity of soils.* Soil Sci. 63(4):277-283.
Small blocks were drained on a porous ceramic cell under a moisture tension of ⅓ atmosphere and the moisture retained in the blocks was related empirically to the field capacity of the same soils determined under natural field conditions.

2051. Colman, E. A.
1947. *Manual instructions for use of the fiberglas soil-moisture instrument.* 17 p. U.S. Forest Serv. Calif.

Forest and Range Exp. Stn., Berkeley, Calif.
Gives calibration instructions for soil moisture instrument developed by the Station.

2052. Colman, E. A., and E. L. Hamilton.
1947. *The San Dimas lysimeters: Part 1. The lysimeter installation and research program. Part 2. The relative performance of four types of lysimeters.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 47, 33 p. Berkeley, Calif.
Discusses the lysimeter installation designed for the purpose of studying the influence of certain species of chaparral vegetation upon the disposition of precipitation reaching the soil.

2053. Colman, E. A.
1948. *Soil surveying on wildlands: The problem and one solution.* J. For. 46(10):755-762.
A soil survey, designed to classify and map wildland soils on the basis of their hydrologic characteristics, demonstrates the value of selecting appropriate methods and using detailed analysis to obtain desired information.

2054. Colman, E. A., and T. M. Hendrix.
1949. *The fiberglas electrical soil-moisture instrument.* Soil Sci. 76(6):425-438.
Describes a soil-moisture measuring instrument and gives the results of significant studies, includes calibration curves, and makes suggestions for further use.

2055. Colman, E. A.
1950. *Hydrological problems of brushland management.* In *Short course on range improvement.* p. 59-65. Hunt Hall Auditorium, Univ. of Calif., Davis. Jan. 31, Feb. 1 and 2, 1950.
Discusses the hydrological consequences of converting brushland to grass by burning.

2056. Colman, E. A.
1951. *Fire and water in southern California's mountains.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 3, 8 p. Berkeley, Calif.
Discusses flood damage resulting from fires in southern California and urges reassessment of fire control policies.

2057. Colman, E. A., and C. B. Brown.
1955. *Measures needed to manage watersheds.* J. Soil and Water Conserv. 10:237-240.
Part 4 in a series of articles on "Protecting and Developing the Nation's Watersheds" describes the place of upstream and downstream operations in watershed management.

2058. Colman, E. A.
1955. *Water control and timber management.* 45th Annu. West. For. Conf. West. For. and Conserv. Assoc. Proc. 1955:24-26.
Discusses ways in which timber production can be integrated with land management for controlling water flow in the Western United States.

2059. Corbett, Edward S., and Lisle R. Green.
1965. *Emergency revegetation to rehabilitate burned watersheds in southern California.* U.S. Forest Serv. Res. Paper PSW-22, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports results of revegetation measures tested, including establishment of seeded grasses and their influence on recovery of native vegetation.

2060. Corbett, Edward S., and Raymond M. Rice.
1966. *Soil slippage increased by brush conversion.* U.S. Forest Serv. Res. Note PSW-128, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A comparison of converted brushland to sites where brush cover recovered naturally showed that both frequency and area of soil slippage were almost five times as great in grass-covered areas as in brush areas.

2061. Corbett, Edward S.
1967. *Measurement and estimation of precipitation on experimental watersheds.* Int. Symp. Forest Hydrol. Proc. 1965:107-129, illus.
Reviews pertinent literature, including types of rain gages, accuracy of point rainfall measurements, selection of rain-gage sites, and precipitation variability.

2062. Corbett, Edward S., and Robert P. Crouse.
1968. *Rainfall interception by annual grass and chaparral . . . losses compared.* USDA Forest Serv. Res. Paper PSW-48, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Loss from grass during three rainy seasons varied from 4.9 percent to 13.5 percent, mature chaparral cover averaged 12.8 percent; grass litter intercepted 4.3 percent of the annual rainfall but this loss must be reduced by the saving in soil evaporation.

2063. Cornelius, Donald R.
1946. *Comparison of some soil-conserving grasses.* Am. Soc. Agron. J. 38(8):682-689.
A mixture of warm-season native tall and mid grasses produced the highest yield of air-dry grass and gave evidence of a satisfactory ability to help control erosion.

2064. Court, Arnold.
1957. *Wind direction during snowfall at Central Sierra Snow Laboratory.* West. Snow Conf. Proc. 1957:39-43.

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2066. Court, Arnold.
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1960. *Reliability of hourly precipitation data.* J. Geophys. Res. 65:1632.
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1960. *Thunderstorm frequency in northern California.* Am. Meteorol. Soc. 41(8):406-409, illus.
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2069. Court, Arnold.
1961. *Larger meltwater flows come later.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 189, 8 p., illus. Berkeley, Calif.
A progress report on studies of methods of describing the time distribution of streamflow through the year.

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1962. *Measures of streamflow timing.* J. Geophys. Res. 67(11):4335-4339, illus.
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2071. Court, Arnold.
1963. *Snowcover relations in the Kings River Basin, California.* J. Geophys. Res. 68:4751-4761.
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2072. Crouse, Robert P.
1961. *First-year effects of land treatment on dry-season streamflow after a fire in southern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 191, 5 p., illus. Berkeley, Calif.
In a period of severe drought, dry-season streamflow increased substantially in two watersheds treated before the fire, whereas in two adjacent non-treated watersheds streamflow had ceased before the fire and did not resume until the next rainy season.

2073. Crouse, Robert P., and L. W. Hill.
1962. *What's happening at San Dimas?* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 68, 6 p., illus. Berkeley, Calif.
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2074. Crouse, Robert P., Edward S. Corbett, and Donald W. Seegrist.
1966. *Methods of measuring and analyzing rainfall interception by grass.* Int. Assoc. Sci. Hydro. IASH Bull. XI[e] Année No. 2, p. 110-120, illus.
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2075. Davis, Wendell E.
1939. *Measurement of precipitation above forest canopies.* J. For. 37(4):324-329.
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2076. DeBano, Leonard F.
1966. *Formation of non-wettable soils . . . involves heat transfer mechanism.* U.S. Forest Serv. Res. Note PSW-132, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Formation of a non-wettable soil layer in brushland soils during fire may involve the volatilization and subsequent condensation of hydrophobic material.

2077. DeBano, Leonard F., and Jay S. Krammes.
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temperatures after which the soil samples were tested for non-wettability.

2078. DeBano, Leonard F., Joseph F. Osborn, Jay S. Krammes, and others.
1967. *Soil wettability and wetting agents . . . our current knowledge of the problem.* U.S. Forest Serv. Res. Paper PSW-43, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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2079. DeBano, Leonard F.
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2080. DeBano, Leonard F.
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2081. DeBano, Leonard F.
1968. *Water movement in water repellent soils.* Symp. Water Repellent Soils, Proc. 1968:61-89, illus. Univ. Calif., Riverside, Calif.
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Summarizes findings on effects of water repellency in moisture movement, factors affecting repellency, and techniques of decreasing repellency.

2083. DeBano, Leonard F., L. D. Mann, and D. A. Hamilton.
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2084. DeBano, Leonard F.
1971. *The effect of hydrophobic substances on water movement during infiltration.* Soil Sci. Soc. Am. 35(2):340-343, illus.
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2085. DeBano, Leonard F., and Raymond M. Rice.
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2086. DeBano, Leonard F., and Raymond M. Rice.
1973. *Water repellent soils: Their implications in forestry.* J. For. 71(4):220-223, illus.
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2087. DeBano, Leonard F.
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2088. DeBano, Leonard F., and C. Eugene Conrad.
1974. *Effect of a wetting agent and nitrogen fertilizer on establishment of ryegrass and mustard on a burned watershed.* J. Range Manage. 27(1):57-60, illus.
The wetting agent decreased plant production by forbs and increased the production of annual grass.

2089. DeBano, Leonard F.
1974. *Forest Soils.* McGraw-Hill Yearb. of Sci. and Technol. p. 204-205, illus. McGraw-Hill Book Co., New York.
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2090. DeBano, Leonard F.
1975. *Infiltration, evaporation, and water movement as related to water repellency.* In *Soil conditioners*, Soil Sci. Soc. Am. Spec. Publ. 7, Chapt. 15, p. 155-164.
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2091. Duffy, Paul D.
1965. *In Hawaiian wildlands water becomes the most important forest crop.* West. Conserv. J. 21(6):58-59.
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2092. Dunford, E. G.
1967. *Forests—users of water.* Soc. Am. For. Proc. 1966:146-150.
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2093. Essington, Edward H., and James L. Smith.
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2094. Fenner, Ralph L., and Jay R. Bentley.
1959. *A fusion pyrometer to measure soil temperatures during wildland fires.* Fire Control Notes 20(4):124-125.
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2095. Fenner, Ralph L., and Jay R. Bentley.
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2098. Gardner, Robert A., and K. E. Bradshaw.
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2099. Gay, Lloyd W.
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1938. *Pickens' Burn a lesson.* West. Trees, Parks and Forests 1(2):6.
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2102. Gleason, Clark H.
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2103. Gleason, Clark H.
1947. *Guide for mustard sowing in burned watersheds of southern California.* 46 p. U.S. Forest Serv., Calif. Region, San Francisco, Calif.
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2104. Gleason, Clark H.
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2108. Gleason, Clark H., Paul E. Packer, and R. D. Hockensmith.
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2111. Gleason, Clark H.
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2113. Goldberg, Irving, Norman A. MacGillivray, and Robert R. Ziemer.
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The effects on soil moisture determination of four different alpha-neutron sources (RaBe, AcBe, PuBe, and AmBe) used in neutron meters were evaluated.

2114. Halverson, Howard G.
1972. *Seasonal snow surface energy balance in a forest opening.* U.S. A.E.C. Tech. Info. Cent. TID-26242, 73 p., illus.
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2115. Hamilton, Everett L.
1933. *The measurement of precipitaiton in mountainous regions.* U.S. Forest Serv. Div. Silvics Transl. No. 334, 3 p.
Translation from the French of *La mesure des precipitations en haute montagne,* from Rev. des Eaux et Forets 71(2):117-118.

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2118. Hamilton, Everett L.
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A study was made of the precipitation on the San Dimas Experimental Forest with reference to the direction and angle of inclination of rainfall and graphic representations of storm patterns were developed which permitted classification of the storms on the basis of direction from which the rain falls.

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2121. Hamilton, Everett L., and P. B. Rowe.
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The root systems of 68 plants, representing 18 species of shrubs and sub-shrubs, were studied, and the importance of the different systems is discussed in relation to erosion and water-yield problems.

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2131. Hill, C. L.
1930. *Orientation of the water use problem from the forester's point of view.* Am. Soc. Civ. Eng. Irrig. Div. Comm. on Conserv. of Water. Proc. of Conf. on Res. Problems in Consumptive Use of Water and Conserv. of Rainfall, March 27-29, 1930:91-95.
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2133. Hill, L. W.
1963. *The cost of converting brush cover to grass for increased water yield*. U.S. Forest Serv. Res. Note PSW-2, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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2134. Hill, L. W.
1963. *The San Dimas Experimental Forest*. 25 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
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2135. Hopkins, Walt.
1958. *More good water—research at San Dimas Experimental Forest applying fundamentals to entire watersheds*. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 22, 6 p., illus. Berkeley, Calif.
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2136. Hopkins, Walt.
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2137. Hopkins, Walt, J. D. Sinclair, and P. B. Rowe.
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2140. Hopkins, Walt, Jay Bentley, and Ray Rice.
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2141. Hopkins, Walt, and Kenneth L. Bowden.
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2142. Horton, Jerome S.
1949. *Trees and shrubs for erosion control in southern California mountains*. 72 p. U.S. Dep. Agric. For. Serv. In cooperation with Calif. Dep. Natural Resour., Div. For.
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2145. Johnson, Paul B.
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2146. Johnson, Paul B.
1944. *Instrument for measuring stream flow*. Civ. Eng. 14(12):523-524.
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Describes a simple, rugged, accurate triangular instrument designed for rapid and easy determination of the zero value on 90° V-notch weirs.

2148. Kojan, Eugene.
1967. *Mechanics and rates of natural soil creep*. Fifth Annu. Eng. Geol. and Soils Eng. Symp., Idaho Dep. Highways, Univ. Idaho State Univ., Pocatello, Proc. 1967:233-253.
Ordinary concepts of effective peak shear strength are not applicable in estimating slope stability where creep is prevalent, especially in soils developing on the rapidly eroding, highly over-consolidated sediments of the Coast Ranges.

2149. Kotok, E. I.
1930. *Influence of forest cover on water supply; investigations relating to south coastal basin, conducted or proposed by the California Forest Experiment Station*. Calif. Dep. Public Works Div. Water Resour. Bull. No. 32, p. 26-33.
Initial tank, surface-plot, and quadrat studies have been valuable in indicating the importance of the soil profile, the vegetative cover and its resultant litter on run-off, seepage and erosion.

2150. Kotok, E. I.
1931. *Erosion: A problem in forestry*. J. For. 29(2):193-198.
Emphasizes the necessity of maintaining a soil cover to check erosion, refers to experiments on the influence of soil cover upon run-off and erosion, and points out that on badly eroded land the forester has the dual job of devising means to check erosion and of starting a new forest.

2151. Kotok, E. I.
1931. *Vegetative cover, the water cycle and erosion*. Agric. Eng. 12(4):112-113.
With accelerated erosion, management must check the abuses at their source whether they are fire, destructive logging, or overgrazing, and the best possible mantle of vegetation must be established.

2152. Kotok, E. I.
1932. *Solving the forest and water riddle*. Am. Forests 38(9):488-491.
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1932. *Solving the water riddle*. Illus. Can. Forest and Outdoors 28(11):415-418.
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2154. Kotok, E. I.
1934. *The work of the California Forest Experiment Station in southern California*. Conserv. Assoc. of Los Angeles County. Proc. Flood Control Conf. 1934:27-31.
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2155. Kotok, E. I.
1935. *Forest influences studies at the San Dimas Experimental Forest*. Am. Soc. Civ. Eng. Irrig. Div. Comm. on Conserv. of Water. Report on progress conference on water conservation. March 13-14, 1935:80-82.
Discusses the complicated character of a watershed, outlines some methods used to isolate and study dynamic factors in varying forest covers such as the capacity to hold and build soil and yield free water, and tells how the forest cover can be manipulated.

2156. Kotok, E. I.
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2157. Kotok, E. I.
1939. *Watershed management for water production*. South. Calif. Water and Soil Conserv. Conf., Los Angeles, 1939:1-4.
Distinguishes between cosmic forces which shape and control geologic processes and man's power to develop

and protect the natural forces at work in the watershed.

2158. Kraebel, Charles J.
1930. *The Barranca watershed study.* Am. Soc. Civ. Eng. Irrig. Div. Comm. on Conserv. of Water. Proc. of Conf. on Res. Problems in Consumptive Use of Water and Conserv. of Rainfall. Los Angeles. March 27-29, 1930:1-7.
After the Barranca watershed was burned and subjected to two winters of erosion and two seasons of vegetative recovery, observations were made on the relation between rainfall and run-off in order to correlate the changing ratios with changing conditions of soil surface and vegetative cover.

2159. Kraebel, Charles J.
1933. *Erosion control on mountain roads, a preliminary manual of procedure.* 5 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Gives directions for six methods of erosion control on roads, including seeded contour trenches, brush wattles, rock terraces, and berm construction.

2160. Kraebel, Charles J., and Arthur F. Pillsbury.
1933. *Use of vegetation for erosion control in mountain meadows.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 2, 13 p. Berkeley, Calif.
Presents several methods to control gullying: the planting of willow cuttings, wattle construction, the planting of sod, and artificial seeding.

2161. Kraebel, Charles J.
1933. *Use of willows to control erosion.* Ala. Forest News 7(10):2-3.
Describes practices and precautions for using willow cuttings as a quick and effective means of securing a vegetative cover for the control of soil erosion.

2162. Kraebel, Charles J.
1933. *Willow cuttings for erosion control.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 1, 3 p. Berkeley, Calif.
Describes how willow cuttings can be used as a quick and effective means of securing a vegetation cover for control of soil erosion.

2163. Kraebel, Charles J.
1934. *The erosion problem in land use.* Paper for Land Use series, Station KPO San Francisco. Aug. 14, 1934. 6 p.
Describes several destructive agents that have increased the erosion rate on 75 percent of cultivated land: agricultural malpractice, fire, overgrazing, bad logging methods, and road building.

2164. Kraebel, Charles J., and Arthur F. Pillsbury.
1934. *Handbook of erosion control in mountain meadows in the California region.* 69 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes the process and causes of meadow erosion, makes recommendations for the control of gullying and for stabilizing slopes by dams, wattles or permanent vegetation, and gives specifications for material and procedure.

2165. Kraebel, Charles J.
1934. *The La Crescenta flood.* Am. Forests 40(6):251-254.
Traces real origin of California's New Year catastrophe to mountain slopes recently swept by fire.

2166. Kraebel, Charles J.
1934. *Outline of procedure in the control of erosion on road slopes.* 3 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Offers several methods with detailed instructions for erosion control on roads including seeded contour trenches, brush wattles, rock terraces, and berm construction.

2167. Kraebel, Charles J.
1934. *Study of the New Year's storm by the California Forest Experiment Station.* Conserv. Assoc. of Los. Angeles County, March 23. Proc. Flood Control Conf. 1934:3-11.
The cause of floods in southern California lies in neither fire nor rain alone, but in the sequence of severe fire followed by intense and heavy rainfall.

2168. Kraebel, Charles J.
1935. *Abstract of runoff and erosion experiments in mountain areas.* Am. Soc. Civ. Eng. Irrig. Div. Comm. on Conserv. of Water Rep. on Progress Conf. on Water Conserv. Los Angeles. March 13-14, 1935:87-95.
The results consistently indicate that vegetation and litter reduce runoff rates from sloping lands, reduce the erosion volume, and induce percolation of water into soil.

2169. Kraebel, Charles J.
1935. *Erosion control on mountain roads; a handbook for the California Region.* 87 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Discusses the serious problem of erosion resulting from motor traffic and road building in mountainous areas and indicates preventive and corrective measures.

2170. Kraebel, Charles J.
1935. *Forest cover proved a controlling factor in flood*

prevention. U.S. Dep. Agric. Yearb. 1935:202-206.
States that the native brush cover in the mountains of California affords a natural control against excessive runoff and destructive erosion.

2171. Kraebel, Charles J.
1935. *Runoff and erosion experiments in mountain areas.* Am. Soc. Civ. Eng. Irrig. Div. Comm. on Conserv. of Water Rep. on Progress Conf. on Water Conserv. Los Angeles, Calif. March 13-14, 1935:87-95.
Results indicate that vegetation and litter function powerfully to reduce the runoff rates on sloping lands, to reduce the volumes of erosion, and to induce the percolation of water into the soil.

2172. Kraebel, Charles J.
1936. *Erosion control on mountain roads.* U.S. Dep. Agric. Circ. No. 380, 45 p. U.S. Gov. Print. Off. Washington, D.C.
Suggests improved location, alignment, bridges, tunnels, retaining walls and drainage for new roads and improvement of drainage and treatment of fill slopes on already existing roads.

2173. Kraebel, Charles J.
1936. *Memorandum on San Antonio Canyon burn of September 16, 1935.* Santa Monica Mt. Fire Prev. Assoc. p. 23-25.
Report and recommendations for fire and flood control in Hollywood Hills and Santa Monica Mountains.

2174. Kraebel, Charles J., and L. F. Kellogg.
1938. *The forest guardians of our watershed.* J. For. 36(9):858-860.
Briefly describes how forest influences research has given a clearer understanding of the watershed forests role in stabilizing streamflow.

2175. Kraebel, Charles J.
1940. *Reduction in debris load through soil conservation and watershed management.* U.S. Natl. Resour. Planning Board. Proc. Meet. South. Calif. Coastal Drainage Basin Comm., Los Angeles. Oct. 10, 1940:20-23.
Estimates the ultimate quantitative effect upon debris movement of a complex program of land treatment for a whole watershed.

2176. Kraebel, Charles J., and J. D. Sinclair.
1940. *The San Dimas Experimental Forest.* Am. Geophys. Union Trans. Vol. 1, 1940:84-92.
Research is conducted on the influences of chaparral vegetation, soils, and geological structure upon the yield of usable water, and methods are developed for managing the chaparral watersheds to obtain the maximum yield with a minimum of erosion.

2177. Kraebel, Charles J.
1954. *A guide to erosion reduction on National Forest timber sale areas.* 78 p. U.S. Forest Serv., Calif. Reg., San Francisco, Calif.
Outlines factors influencing watershed conditions in logging areas, discusses watershed damage caused by logging practices, and describes road building and logging practices designed to preserve the stability of soil and stream channels.

2178. Kraebel, Charles J.
1955. *Conquering Kennett's gullies.* Am. Forests 61(12):36-39, 42, 44.
Describes the killing of forest cover by smelter fumes 50 years ago in northern California, subsequent erosion of the bared slopes, studies that developed successful methods of reforestation and erosion control, and recent application of the methods on the area.

2179. Krammes, Jay S.
1960. *Erosion from mountain side slopes following fire in southern California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 171, 8 p., illus. Berkeley, Calif.
During the first year after the native vegetation was burned, erosion ranged from 2.2 to 24.7 tons per acre; nearly 89 percent of the erosion occurred during the dry season.

2180. Krammes, Jay S., and L. W. Hill.
1963. *'First aid' for burned watersheds.* U.S. Forest Serv. Res. Note PSW-29, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes quantitative results of a research program which tested several treatments aimed at reducing flood and erosion damage on burned watersheds.

2181. Krammes, Jay S., and Henry Hellmers.
1963. *Tests of chemical treatments to reduce erosion from burned watersheds.* J. Geophys. Res. 68:3667-3672, illus.
Soil binding chemicals increased surface runoff and debris production, whereas a 'wet' water treatment resulted in added infiltration and in less runoff.

2182. Krammes, Jay S., and Raymond M. Rice.
1964. *Effect of fire on the San Dimas Experimental Forest.* Seventh Annu. Ariz. Watershed Symp. Proc. 1963:31-34.
Summarizes major research emphasis of the Experimental Forest before a wildfire and describes rehabilitation methods tested afterward which were aimed at reducing flood peaks and debris from burned watersheds.

2183. Krammes, Jay S.
1965. *Seasonal debris movement from steep mountain slide slopes in southern California.* Fed. Interagency Sediment. Conf. Proc. 1963, Paper 12:85-88.
Summarizes debris measurements during a 9-year period at nine sites in the San Gabriel Mountains.

2184. Krammes, Jay S., and Leonard F. DeBano.
1965. *Soil wettability: A neglected factor in watershed management.* Water Resour. Res. 1(2):283-286, illus.
Uneven soil-moisture penetration, which has been observed after several wildfires, is associated with an organic coating on the soil particles which makes the soil hydrophobic.

2185. Krammes, Jay S., J. D. Lent, and J. W. Clarke.
1965. *Streamflow records from the San Dimas Experimental Forest, 1939-1959.* U.S. Forest Serv. Res. Note PSW-79, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes hydrographs, covering 314 station-years of record, from mean daily streamflow tables, and flood peak tables.

2186. Krammes, Jay S., and Leonard F. DeBano.
1967. *Leachability of a wetting-agent treatment for water-resistant soils.* Soil Sci. Soc. Am. Proc. 31(5):709-711, illus.
Results from a laboratory leaching study showed that the wetting agent treatment persisted after 40 cm of water had passed through soil samples.

2187. Krammes, Jay S., and J. Osborn
1969. *Water repellent soils and wetting agents as factors influencing erosion.* Symp. Water Repellent Soils Proc., Univ. Calif., Riverside, Calif., 1968:177-187, illus.
A wetting agent treatment significantly reduced erosion and surface runoff from several post-fire study areas in southern California.

2188. Krammes, Jay S., and David M. Burns.
1973. *Road construction on Caspar Creek watersheds . . . 10-year report on impact.* USDA Forest Serv. Res. Paper PSW-93, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Generally, fish habitat and fish populations in these California watersheds have not been materially affected by road building, but suspended sediment yields were above normal in 3 of the 4 study years.

2189. Krouse, H. Roy, and James L. Smith.
1973. *O^{18}/O^{16} abundance variations in Sierra Nevada seasonal snowpacks and their use in hydrological research.* Proc. Int. Hydrol. Decade Snow and Ice Symp., Banff, Canada, Sept. 1972:24-38, illus.
When ice layers are formed, the identification of seasonal trends in glaciers is extremely difficult and subject to misinterpretation.

2190. Limpert, Fred A., and James L. Smith.
1974. *Utility of isotope profiling snow gage for water management.* In *Advanced concepts and techniques in the study of snow and ice resources,* p. 624-631. Henry S. Santeford and James L. Smith, comp. Natl. Acad. Sci., Washington, D.C.
Experience to date with the isotope profiling snow gage indicates this instrument will be a valuable adjunct to the hydrometeorological network.

2191. Linlor, William I., and James L. Smith.
1974. *Electronic measurements of snow sample wetness.* In *Advanced concepts and techniques in the study of snow and ice resources,* p. 720-728. Henry S. Santeford and James L. Smith, comp. Natl. Acad. Sci., Washington, D.C.
Describes two methods for measuring wetness of snow—one based on change in capacitance of snow sample before and after freezing, and the other based on losses in a resonating electrical circuit.

2192. Linlor, William I., Mark F. Meier, and James L. Smith.
1974. *Microwave profiling of snowpack free-water content.* In *Advanced concepts and techniques in the study of snow and ice resources,* p. 729-736. Henry S. Santeford and James L. Smith, comp. Natl. Acad. Sci., Washington, D.C.
Microwave measurements of snow wetness appear capable of yielding reasonably precise profiles without affecting the physical properties of the snowpack.

2193. Linlor, William I., Fred D. Clapp, Mark F. Meier, and James L. Smith.
1975. *Snow wetness measurements for melt forecasting.* In *Operational Applications of Satellite Snowcover Observations,* Proc. Workshop, South Lake Tahoe, Calif. Aug. 18-20, 1975. Natl. Aeronautics and Space Admin., NASA SP-391, p. 375-397.
Describes a technique that uses satellite telemetry and is based on the attenuation of a microwave beam in transmission through snow.

2194. Lowdermilk, W. C.
1927. *Factors influencing the surface run-off of rainfall.* First Int. Congr. Soil Sci. Washington, D.C. Vol. 6, 1927:84-85.
Serious erosion and flooding can result from a superficial rainfall runoff, due to the accumulation of shallow local seepage and perennial springs.

2195. Lowdermilk, W. C.
1928. *Forest litter aids in conserving water for California farms.* U.S. Dep. Agric. Yearb. 1928:326-327.
Accumulated litter on the soil performs the important functions of keeping open the pores and seepage channels into the mountain soils, and spreading flood waters to sink and store such waters in deep underground basins.

2196. Lowdermilk, W. C.
1928. *The water cycle, a discussion of theoretical considerations and the point at which practical application may be made.* J. For. 26(3):352-354.
Discusses the direct relationship of river discharge and its ocean source, points out that the silt content of runoff provides an indicator fcr watershed control, and concludes that success in water control can be measured by success in erosion control.

2197. Lowdermilk, W. C.
1929. *Erosion in the Orient as related to soil conservation in America.* Am. Soc. Agron. J. 21(4):404-414.
Considers the erosional processes which human occupation in China and Korea has accelerated and stresses the need for constructive soil management to save enormous losses in land values and production.

2198. Lowdermilk, W. C.
1929. *Further studies of factors affecting surficial runoff and erosion.* Int. Contr. For. Exp. Stns. Stockholm. Proc. p. 606-628.
Eight experimental tanks were designed and installed to provide for soil profiles of 2.5 feet, for projectional soil surfaces of 10 square feet, sloping at a 30 percent gradient, for collection and measurement of surficial runoff, for elutriation of eroded material, and for the collection and measurement of seepage through the soil profiles.

2199. Lowdermilk, W. C.
1930. *An analysis of factors affecting the yield of water from watersheds in southern California.* 14 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Examines the supply and disposition of water in the chaparral and brush forests which cover water yielding drainages.

2200. Lowdermilk, W. C., and T. I. Li.
1930. *Forestry in denuded China.* Am. Acad. Polit. and Social Sci. Ann. Vol. 152, p. 127-141.
States that there exists in China a great need to increase the local production of wood construction materials and that erosion control is necessary for the sustained productivity of the land.

2201. Lowdermilk, W. C.
1930. *Influence of forest litter on run-off, percolation, and erosion.* J. For. 28(4):474-491.
Experiments show that litter greatly reduced runoff, destruction of litter increased the amount of eroded material and reduced the absorption rate of the soil.

2202. Lowdermilk, W. C.
1930. *Studies of factors affecting the yield of water from watersheds in southern California.* Am. Soc. Civ. Eng. Irrig. Div. Comm. on Conserv. of Water. Proc. of Conf. on Res. Problems in Consumptive Use of Water and Conserv. of Rainfall. Los Angeles. March 27-28, 1930:H 1-22.
Presents a three-page bibliography containing material on streamflow, erosion, surface runoff, forest influences, and floods.

2203. Lowdermilk, W. C.
1931. *Certain problems in the management of watersheds for maximum beneficial water production.* Ventura County, Calif. Farm Bureau. Conserv. Comm. Proc. Ventura County Conserv. Day, May 11, 1931:7-13.
Examines the process of retention in watersheds, and suggests robbing canyon bottom vegetation of drainage flow by piping water out to increase the water yield.

2204. Lowdermilk, W. C.
1931. *Managing brush and forest lands primarily for yield of irrigation water.* Second Natl. Water Users Conf., San Francisco, Feb. 9-11, 1931.
Considers the influence of a brush woodland forest on rain intensities, and disposition by retention, runoff, seepage, evaporation and transpiration, and suggests storing water in reservoirs or by sinking it into underground basins.

2205. Lowdermilk, W. C.
1931. *Studies of the role of forest vegetation in surficial run-off and soil erosion.* Agric. Eng. 12(4):107-112.
Natural vegetation with its layer of ground litter is the most effective agent in maintaining the maximum absorption rate of soils and in maintaining the geologic norm of erosion.

2206. Lowdermilk, W. C.
1933. *Forests and stream flow—discussion of the Hoyt-Troxell report.* J. For. 31(3):296-307.
Analyzes the Hoyt-Troxell report which attacked the belief that watershed vegetation must be kept intact for the most favorable influence upon streamflow, erosion, and flood control, points out contradictions and conflicting evidence, and calls for further research.

2207. Lowdermilk, W. C.
1933. *Studies in the role of forest vegetation on erosion control and water conservation.* Pacific Sci. Congr. 5th, Victoria and Vancouver, B. C., 1933. Proc. Vol. 5, p. 3963-3990.
Experiments show that baring soil of natural vegetation reduces the absorption rate of a soil profile for water, surficial runoff is increased under high rain intensities, and accelerated erosion proceeds at rates in excess of those of soil formation, causing final destruction of soils.

2208. Lowdermilk, W. C.
1934. *Acceleration of erosion above geologic norms.* Am. Geophys. Union Trans. 15th Annu. Meet. 1934:505-509.
Clarifies the differentiation between geologic norms of erosion and accelerated erosion; soils are rarely destroyed by the former whereas the latter truncates soil-profiles and in time destroys the soil.

2209. Lowdermilk, W. C.
1934. *Considerations in measurement of yield of snow packs in percolation water.* West. Interstate Snow Survey Conf., Reno. Proc. p. 35-37.
A modified rain retention pan was used to hold soil columns from 4 to 36 inches in depth for measuring the losses of rainfall by evaporation.

2210. Lowdermilk, W. C., and P. B. Rowe.
1934. *Still further studies on absorption of rainfall in its relations to surficial runoff and erosion.* Am. Geophys. Union Trans. 15th Annu. Meet. 1934:509-515.
Concludes that a mantle of undisturbed vegetation serves in heavy rain-storms to maintain the soil at high rates of absorption, and that baring the soil increases surficial runoff and erosion.

2211. Lowdermilk, W. C.
1935. *Soil erosion and its control in the United States.* Trans. Third Int. Congr. Soil Sci. Oxford, Eng., 1935. Vol. 2, p. 181-194. Also, Congr. Rec. Appendix, Jan. 27, 1936:1113-1117.
Reviews the condition of the American continent when the English colonists cleared their first corn fields, the present condition of the lands and the measures that are being taken to meet the problem of soil erosion.

2212. Lull, Howard W., and Henry W. Anderson.
1967. *Important watershed characteristics affecting water yield flood peaks, and erosion and sedimentation and the basic data needed for prediction.* Int. Conf. Water for Peace, P431, 8 p. Washington, D.C.
Predictions of water yield, floods, erosion, and sedimentation must take into account the environmental factors, the nature of the watershed, and its past history.

2213. McDonald, Philip M.
1967. *Disposition of soil moisture held in temporary storage in large pores.* Soil Sci. 103(2):139-143, illus.
A soil moisture probe with a neutron source was used to evaluate the lateral flow of subsurface water in detention storage.

2214. McMillan, Michael C., and James L. Smith.
1975. *Remote sensing of snowpack density using shortwave radiation.* In *Operational application of satellite snowcover observations,* Proc. Workshop, South Lake Tahoe, Calif., Aug. 18-20, 1975. Natl. Aeronautics and Space Admin. NASA SP-391, p. 361-371.
Albedo or satellite radiance measurements can be used to estimate average snowpack density by means of a multiple linear equation.

2215. Merriam, Robert A.
1959. *Nuclear probe compared with other soil moisture measurement methods.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 146, 5 p., illus. Berkeley, Calif.
The gravimetric, Colman unit, and nuclear probe methods of measuring soil moisture gave similar results when tested at the San Dimas Experimental Forest in lysimeter soils 6 feet deep.

2216. Merriam, Robert A.
1960. *Moisture sampling in wildland soils with a neutron probe.* Iowa State J. Sci. 34(4):641-648.
Explains the theory of the neutron probe for measuring soil moisture, describes the equipment and its operation, and discusses the advantages and disadvantages of the neutron probe.

2217. Merriam, Robert A., and Kenneth R. Knoerr.
1961. *Counting times required with neutron soil moisture probes.* Soil Sci. 92(6):394-395, illus.
An equation is derived for the error of soil moisture determination with a neutron probe.

2218. Merriam, Robert A.
1961. *A note on the interception loss equation.* J. Geophys. Res. 65(11):3850-3851, illus.
Proposes an exponential interception loss equation describing the observed relationship between interception loss and total storm rainfall over the entire range of precipitation values.

2219. Merriam, Robert A.
1961. *Saving water through chemical brush control.* J. Soil and Water Conserv. 16(2):84-85, illus.

Water losses by evapotranspiration from dense brush growing on deep soil were greatly reduced after killing the brush with 2,4,5-T herbicide.

2220. Merriam, Robert A.
1961. *Surface water storage on annual ryegrass.* J. Geophys. Res. 66(6):1833-1838, illus.
This article shows that surface ratio also is a factor in the storage component of interception loss.

2221. Merriam, Robert A.
1971. *Forests and water: some questions answered.* Aloha Aina, Jan. 1971:12-14, illus.
Provides answers to some of the most commonly asked questions about the forests of Hawaii and their relation to water supply.

2222. Merriam, Robert A.
1973. *Fog drip from artificial leaves in a fog-wind tunnel.* Water Resour. Res. 9(6):1591-1598, illus.
A small low-velocity wind and fog tunnel was built and used to study the storage of water on and drip from artificial leaves of aluminum and plastic.

2223. Miller, David H.
1962. *Snow in the trees—where does it go?* Proc. West. Snow Conf. 1962:21-27.
Destination of intercepted snow moving out of tree crowns can best be studied by analyzing data from diverse sources on mechanical and thermodynamic processes, their energy requirements, and limiting conditions of radiative and advective heat supply and vapor-pressure gradient.

2224. Miller, David H.
1964. *Interception processes during snowstorms.* U.S. Forest Serv. Res. Paper PSW-18, 24 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Four processes are identified as determining the initial interception of falling snow by a forest: delivery of snow particles from the airstream to the forest, true throughfall of particles to the forest floor, impaction and adhesion of particles to foliage and branches, and cohesion of particles into masses of snow.

2225. Miller, David H.
1966. *Transport of intercepted snow from trees during snow storms.* U.S. Forest Serv. Res. Paper PSW-33, 30 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Five principal processes by which intercepted snow in trees is removed are described: vapor flux from melt water, vapor flux from bodies of snow, stem flow and dripping of melt water, sliding of bodies of intercepted snow from branches, and wind erosion and transport of intercepted snow.

2226. Munson, S. M.
1938. *Kings River branch watershed study units.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 11, 12 p. Berkeley, Calif.
Summarizes studies designed to determine the basis of management for forest areas from the maximum yield of usable water, and presents maps and photographs of experimental installations to measure erosion and flood peaks.

2227. Nelson, Robert E.
1965. *Watersheds assume important role in forest management in Hawaii.* West. Conserv. J. 21(6):56-57, illus.
A comprehensive coordinated program of forestry research seeks new knowledge basic to efficient development and use of Hawaii's forest resources.

2228. Newhall, George N., and James L. Smith.
1965. *Watershed management: Effects on basin development.* Proc. Am. Soc. Civ. Eng. Billings Conf. of Irrig. and Drainage Div. 1965:47-86.
Storage and loss determination for watersheds, treatments for erosion control and snowpack management are discussed.

2229. Osborn, Joseph F., R. E. Pelishek, Jay S. Krammes, and J. Letey.
1964. *Soil wettability as a factor in erodibility.* Soil Sci. Soc. Am. Proc. Vol. 28, No. 2, March-April 1964:294-295.
A field study undertaken to determine the erosion and surface runoff from hydrophobic soils treated with a wetting agent showed that the treatment significantly reduced erosion and benefited vegetative growth.

2230. Patric, James H.
1959. *Increasing water yield in southern California mountains.* J. Am. Water Works Assoc. 51(4):474-480, illus.
Reports methods and some first results of removing canyon-bottom trees and replacing hillside brush with grasses in pilot tests at the San Dimas Experimental Forest.

2231. Patric, James H.
1961. *A forester looks at lysimeters.* J. For. 59(12):889-893, illus.
Concludes that lysimeters have a place in forestry research, but cautions that lysimeter results are relative and should not be applied directly to natural forest situations.

2232. Patric, James H.
1961. *The San Dimas large lysimeters.* J. Soil and Water Conserv. 16(1):13-17, illus.
A description of the establishment of the large lysimeters, the research program conducted, and some conclusions resulting from the experiments.

2233. Perenin, R. F. (Trans.)
1935. *Flood control of torrential streams, by V. Kaisler.* U.S. Forest Serv. Div. of Silvics. Transl. No. 157, 13 p.
Floods in the 1880's in the southern Alps stimulated the organization of forest and pastoral management, including plantations and the systematic distribution of check dams to lessen high waters.

2234. Rice, Raymond M.
1963. *It's not over when the fire's out.* 4 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Accelerated erosion and high floods often result from brush fires in southern California's mountains.

2235. Rice, Raymond M., Robert P. Crouse, and Edward S. Corbett.
1965. *Emergency measures to control erosion after a fire on the San Dimas Experimental Forest.* U.S. Dep. Agric. Misc. Publ. 970, p. 122-130, illus.
From measurements made during four moderate sized storms in the 1962 hydrologic year it was concluded that side slope stabilization by contour furrow planting with barley was the most effective erosion control treatment.

2236. Rice, Raymond M.
1967. *Multivariate methods useful in hydrology.* Int. Hydrol. Symp. Proc. 1967(1):471-478, illus.
Suggests that hydrologists should use multivariate statistical methods whenever appropriate so that they may benefit from the advantages of these techniques.

2237. Rice, Raymond M., Edward S. Corbett, and Robert G. Bailey.
1969. *Soil slips related to vegetation, topography, and soil in southern California.* Water Resour. Res. 5(3):647-659, illus.
Reports that all soil slips occurred on slopes greater than 80 percent and that the occurrence of slips was inversely related to the size and density of vegetation.

2238. Rice, Raymond M., and G. Thomas Foggin, III.
1970. *The effect of high intensity storms on soil slippage on mountainous watersheds in southern California.* Water Resour. Res. 7(6):1485-1496, illus.
Soil slippage occurred on 5.5 percent of the brush area and 16.7 percent of the grass area.

2239. Rice, Raymond M.
1970. *Factor analyses for the interpretation of basin physiography.* Proc. Int. Hydrol. Symp., Wellington, N.Z., 1970:253-268.
Factor analysis led to hypotheses, but it did not lead to the selection of a set of variables having any great utility in the prediction of flood runoff.

2240. Rice, Raymond M., and Joseph F. Osborn.
1970. *Wetting agent fails to curb erosion from burning watershed.* USDA Forest Serv. Res. Note PSW-219, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A pilot watershed test of the use of a wetting agent to control postfire erosion showed that the treatment had no effect.

2241. Rice, Raymond M., and Jay S. Krammes.
1971. *Mass-wasting processes in watershed management.* Proc. Symp. on Interdisciplinary Aspects of Watershed Manage., Bozeman, Mont., 1970:231-259, illus.
Erosion by mass-wasting processes, such as soil creep and dry creep, are unspectacular and others, such as landslides, occur infrequently.

2242. Rice, Raymond M., J. S., Rothacher, and W. F. Megahan.
1972. *Erosional consequences of timber harvesting: an appraisal.* Proc. Natl. Symp. Watersheds in Trans. Fort Collins, Colo. 1972:321-329.
Summarizes current understanding of the effect of logging on erosion, with emphasis on the effects of fire and landslides.

2243. Rice, Raymond M.
1972. *Using canonical correlation for hydrological predictions.* Bull. Int. Assoc. Hydrol. Sci. 17(3):315-321, illus.
Canonical correlation was found to be mathematically equivalent to multiple regression when used for predicting multiple dependent variables.

2244. Rice, Raymond M.
1974. *The hydrology of chaparral watersheds.* Proc., Symp. on Living with the Chaparral, Riverside, Calif., 1973:27-34. Sierra Club, San Francisco, Calif.
Gravity processes of dry ravel and landslides are estimated to account for 80 percent of the erosion on side slopes of chaparral watersheds in southern California.

2245. Roof, Sharon D.
1961. *Computer program available for constructing streamflow rating tables.* U.S. Forest Serv. Pacific

Southwest Forest and Range Exp. Stn. Res. Note 185, 1 p. Berkeley, Calif.
Announces an IBM 704 program for constructing rating tables.

2246. Rowe, P. B.
1933. *Erosion control studies of the Juncal Reservoir.* Conserv. Act. 1(3):9-11.
Measures a special erosion control problem on a denuded watershed yielding information valuable in future flood control and erosion studies.

2247. Rowe, P. B., D. M. Ilch, and R. Bollaert.
1937. *An infiltration study of a denuded and a forest covered soil.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 14, 3 p. Berkeley, Calif.
Studies the extent of the influence of forest cover on developing and maintaining soil permeability.

2248. Rowe, P. B.
1940. *The construction, operation, and use of the North Fork infiltrometer.* 64 p. U.S. Dep. Agric. Flood Control Coord. Comm. Misc. Publ. No. 1, and U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Publ. No. 1.
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2249. Rowe, P. B.
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1941. *Some factors of the hydrology of the Sierra Nevada foothills.* Am. Geophys. Union Trans. 1941:90-100.
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2251. Rowe, P. B.
1943. *A method of hydrologic analysis in watershed-management.* Am. Geophys. Union Trans. 1943:632-643.
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2252. Rowe, P. B.
1945. *Contribution to Report of the Committee on Transpiration and Evaporation, 1943-44.* Am. Geophys. Union Trans. Pt. V, 1945:685-686.
Studies have shown that under California conditions of heavy rainfall in winter and very light rainfall in summer, interception losses due to direct evaporation from the vegetation are much lower than previously supposed.

2253. Rowe, P. B.
1948. *Influence of woodland chaparral on water and soil in central California.* 70 p. U.S. Dep. Agric. Forest Serv. in cooperation with Calif. Dep. Nat. Resour., Div. of For.
Experiments showed that the removal of vegetation causes a decided reduction in infiltration capacity of the soil which caused accelerated surface runoff and erosion.

2254. Rowe, P. B., and E. A. Colman.
1951. *Disposition of rainfall in two mountain areas of California.* USDA Tech. Bull. No. 1048, 84 p. U.S. Gov. Print. Off., Washington, D.C.
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2255. Rowe, P. B., Clive M. Countryman, and Herbert C. Storey.
1954. *Hydrological analysis used to determine effects of fire on peak discharge and erosion rates in southern California watersheds.* 49 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Berkeley, Calif.
Describes procedures of hydrologic analysis used in appraising the effects of watershed burning upon flood damage.

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1955. *Effects of the forest floor on disposition of rainfall in pine stands.* J. For. 53:342-348.
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2257. Rowe, P. B., and E. A. Colman.
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2258. Rowe, P. B.
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2259. Rowe, P. B., and Lyle V. Reimann.
1961. *Water use by brush, grass, and grass-forb vegetation.* J. For. 59(3):175-181, illus.
Reduction in water use by converting brush to annual grass occurred only on soil more than 3 feet deep when rainfall was sufficient to wet through the soil and when regrowth of brush or invasion of other deep-rooted plants was controlled.

2260. Rowe, P. B.
1963. *Streamflow increases after removing woodland-riparian vegetation from a southern California watershed.* J. For. 61:365-370, illus.
Stream flow yields can be appreciably increased by clearing the deep-rooted vegetation from selected canyon bottom reaches.

2261. Sinclair, J. D., and Everett L. Hamilton.
1936. *Watershed management research; the San Dimas Experimental Forest.* Trails Mag. 3(2):17, 20-21.
Describes the extensive outdoor laboratory of the Experimental Forest, focusing on the program of research investigating rainfall, geology, streamflow, soils and vegetation on the watershed.

2262. Sinclair, J. D., and Everett L. Hamilton.
1953. *A guide to the San Dimas Experimental Forest, Glendora, California.* 19 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Short synopsis of current work and publications of the Experimental Forest.

2263. Sinclair, J. D.
1954. *Erosion in the San Gabriel Mountains of California.* Am. Geophys. Union Trans. 35(2):264-268.
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2264. Sinclair, J. D., and Everett L. Hamilton.
1955. *Streamflow reactions of a fire-damaged watershed.* A.S.C.E. Proc., Vol. 81, Sep. 629, 17 p.
Presents relations between peak flows and between storm discharges from two comparable watersheds on the San Dimas Experimental Forest before and after a fire in 1953 partially burned one of the watersheds.

2265. Sinclair, J. D., and James H. Patric.
1959. *The San Dimas disturbed soil lysimeters.* Int. Union of Geodesy and Geophys. Symp. on Woodlands and Water, Proc. 1959:116-125.
Describes large confined and unconfined lysimeters, compares the growth of pine in the two types, and discusses the influence of plant species on rainfall disposition in the confined lysimeters.

2266. Sinclair, J. D.
1960. *Watershed management research in southern California's brush covered mountains.* J. For. 58(4):266-268.
Research has shown that water yields and losses are influenced by the vegetative cover and depth of soil as well as amount of rainfall.

2267. Smith, James L., and Don W. Willen.
1964. *Radio snow-gage: a review of the literature.* Isot. and Radiat. Technol. 2(1):41-49.
Since 1950 over 20 publications have reported research concerning the use of radioactive sources to measure snow water content; the major findings from the literature are presented along with a bibliography.

2268. Smith, James L., Donald Willen, and Michael S. Owens.
1965. *A gamm-transmission gage for profiling snowpack.* U.S. A.E.C. Isot. Syst. Dev. Conf. Proc. 1965:36.
It is possible to profile a snowpack in one-half inch vertical increments and obtain accuracy in snow density measurements to within 1.2 percent of actual density.

2269. Smith, James L., Donald W. Willen, and Michael S. Owens.
1965. *Measurement of snowpack profiles with radioactive isotopes.* Weatherwise 18(6):246-251, 257, 287.
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2270. Smith, James L.
1966. *Isotopes—a multipurpose tool for forest watershed research.* Int. Symp. on Forest Hydrol. Proc. 1965:771-778.
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2271. Smith, James L., Donald W. Willen, and Michael S. Owens.
1966. *Portable radioactive isotope snow gages for profiling snowpacks.* U.S. A.E.C. Div. Tech. Inf., TID-23368, 51 p., illus.
Describes battery-operated neutron and gamma scatter gages.

2272. Smith, James L., and Donald W. Willen.
1967. *Gamma-transmission profiling radioisotope snow density and depth gage.* West. Snow Conf. Proc. 1966. 18 p.
A gamma-transmission system can be used to determine density increases due to snowmelt or rain on snow, and there is no effect on attenuation by the different forms of water.

2273. Smith, James L.
1967. *Instrumentation for snow gaging—yesterday, today, and tomorrow.* Isot. and Radiat. Technol. 4(3):227-237.
Development of three systems of snow gaging, gravimetric methods, weighing platforms, and nuclear gages, is described, along with their advantages and disadvantages.

2274. Smith, James L., Donald W. Willen, and Michael S. Owens.
1967. *Isotope snow gages for determining hydrologic characteristics on snowpacks.* Geophy. Monogr. 11:11-21, illus.
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2275. Smith, James L.
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2276. Smith, James L., and Howard G. Halverson.
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2277. Smith, James L., Howard G. Halverson, and Ronald A. Jones.
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2278. Smith, James L., Howard G. Halverson, and Ronald A. Jones.
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2279. Smith, James L., and Howard G. Halverson.
1971. *Suppression of evaporation losses from snowpacks.* Proc. Symp. on Interdisciplinary Aspects of Watershed Manage., Bozeman, Mont. 1970:5-25.
Suppression of evaporation may be achieved with use of long-chain-fatty alcohol monolayers; 12 pounds per acre is sufficient to achieve maximum evaporation reduction.

2280. Smith, James L., Howard G. Halverson, and Ronald A. Jones.
1972. *Central Sierra profiling snow gage: A guide to fabrication and operation.* U.S. A.E.C. Div. Tech. Inf. Cent. TID-25986, 53 p., illus.
Provides instructions for the manufacture, calibration, operation, and data reduction of the central Sierra profiling snow gage.

2281. Smith, James L., Howard G. Halverson, and Ronald A. Jones.
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2282. Smith, James L.
1972. *Forest soils and the associated soil-plant water regime.* In *Isotopes and radiation on soil-plant relationships, including forestry,* p. 399-412. Vienna, Austria: Int. Atomic Energy Agency, 1972.
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2283. Smith, James L.
1974. *Hydrology of warm snowpacks and their effects upon water delivery . . . some new concepts.* In *Advanced concepts and techniques in the study of snow and ice resources,* p. 76-89. Natl. Acad. of Sci. Washington, D.C.
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2284. Smith, James L.
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Describes the basic processes that affect the accumulation and melt of snow in the Sierra Nevada, and how timber harvest can affect water yield in a planned manner.

2285. Stahelin, Rudolph.
1934. *La signification de l'inondation de Los Angeles au point de vue forestier. (Significance of the Los Angeles flood from the forestry point of view).* J. For. Suisse 85(7):152-157.
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2286. Talbot, M. W., and Charles J. Kraebel.
1944. *Relation of forest lands to agriculture, industry, and people in southern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 39, 5 p. Berkeley, Calif.
Outlines some steps that must be taken to preserve and protect the forest watersheds, where the problems of water supply, flood and erosion are among the most serious in the United States.

2287. U.S. Forest Serv., California Forest and Range Experiment Station.
1951. *Some aspects of watershed management in southern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 1, 29 p. Berkeley, Calif.
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2288. U.S. Forest Serv., California Forest and Range Experiment Station.
1954. *Fire-flood sequences on the San Dimas Experimental Forest.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 6, 22 p. Berkeley, Calif.
Describes how a brush fire burned into experimental watersheds of the San Dimas Experimental Forest and gives account and analytical discussion of flood flows resulting from heavy rains on the fire-damaged watershed.

2289. U.S. Forest Serv., Pacific Southwest Forest and Range Experiment Station.
1959. *Managing our snow for a better water supply.* 17 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. and Calif. Dep. Water Resour.
A "picture book" describing the California Cooperative Snow Management Research Program.

2290. Van't Woudt, Bessel D., and Robert E. Nelson.
1963. *Hydrology of the Alakai Swamp, Kauai, Hawaii.* Hawaii Agric. Exp. Stn. Bull. 132, 30 p., illus.
During prolonged dry spells a continued base-flow of 100 acre-feet per day in the Waimea and Makaweli rivers can probably be counted upon, derived from subsurface storage below the Alakai swamp above 3000-feet elevation.

2291. Wallis, James, and Lee J. Stevan.
1961. *Erodibility of some California wildland soils related to their metallic cation exchange capacity.* J. Geophys. Res. 66(4):1225-1230, illus.
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2292. Wallis, James R., and Donald W. Willen.
1963. *Variation in dispersion ratio, surface aggregation ratio, and texture of some California surface soils as related to soil-forming factors.* Bull. Int. Assoc. Sci. Hydrol. 8 Année No. 4, 48-58.
Samples of the residual mineral soil were taken from 258 locations and standard textural, organic matter, and erodibility analyses were made.

2293. Wallis, James R., and Henry W. Anderson.
1965. *An application of multivariate analysis to sediment network design.* Bull. Int. Assoc. Sci. Hydrol. 68(1):357-378, illus.
Analysis suggests that for some stations the number of sediment samples taken could be greatly reduced without impairing the accuracy of predicted sediment yield and that in addition, samples need to be taken on other watersheds.

2294. Wallis, James R.
1965. *Multivariate statistical methods in hydrology—a comparison using data of known functional relationship.* Water Resour. Res. 1(4):447-461.
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2295. West, Allan J., and Kenneth R. Knoerr.
1959. *Water losses in the Sierra Nevada.* J. Am. Water Works Assoc. 51(4):481-488, illus.
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2296. Willen, Donald W.
1965. *Surface soil textural and potential erodibility characteristics of some southern Sierra Nevada forest sites.* Soil Sci. Soc. Am. Proc. 29(2):213-218.
Multiple regression tests showed that soil texture and erodibility indexes were significantly related to variation in parent rock type, vegetative cover type, aspect, slope, and elevation.

2297. Wilm, H. G., John S. Cotton, and Herbert C. Storey.
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A new design of critical-depth flume was developed which makes a reasonable accurate measurement of small and intermediate loaded flows.

2298. Wilm, H. G., A. Z. Nelson, and Herbert C. Storey.
1939. *An analysis of precipitation measurements on mountain watersheds.* Monthly Weather Rev. 67(6):163-172.
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2299. Wilm, H. G. (Transl.)
1939. *Investigations and results of research into the influence of vegetation on streamflow from the mountain drainage basins of Kychova and Zdechovka 1928 to 1934 by Z. Valek.* U.S. Forest Serv. Div. of Forest Manage. Res. Transl. No. 365, 12 p.
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1944. *Velocity-head rod calibrated for measuring stream flow.* Civ. Eng. 14(11):475-476.
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2301. Wood, Hulton B., Robert A. Merriam, and Thomas H. Schubert.
1969. *Vegetation recovering . . . little erosion on Hanalei watershed after fire.* USDA Forest Serv. Res. Note PSW-191, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Four months after a fire, 86 percent of a transect length had vegetation cover of less than 50 percent whereas ten months after the fire, 94 percent of the transect length had greater than 50 percent vegetation density.

2302. Wood, Hulton B.
1971. *Land use and its effects on the hydrologic characteristics of some Hawaii soils.* J. Soil and Water Conserv. 26(4):158-160, illus.
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2303. Wyckoff, P. E.
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2304. Wyckoff, Stephen N.
1948. *California's watersheds.* J. For. 46(2):99-103.
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2305. Yamamoto, Teruo.
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2306. Yamamoto, Teruo.
1963. *Soil moisture constants and physical properties of selected soils in Hawaii.* U.S. Forest Serv. Res. Paper PSW-2, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Data representing known land use are grouped into four categories: forest, cultivated area, pasture, and idle grassland.

2307. Yamamoto, Teruo, and Paul Duffy.
1963. *Water storage capacities of soil under four different land uses in Hawaii.* U.S. Forest Serv. Res. Note PSW-5, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Pore volume and pore size were higher under forest cover than under cultivation, pasture, or idle grassland.

2308. Yamamoto, Teruo, and Henry W. Anderson.
1967. *Erodibility indices for wildland soils on Oahu, Hawaii, as related to soil forming factors.* Water Resour. Res. 3(3):785-798, illus.
Parent material of volcanic ash was the most essential factor in explaining variance of water stable aggregates of Hawaiian soils.

2309. Yamamoto, Teruo, and Henry W. Anderson.
1973. *Splash erosion related to soil erodibility indexes and other forest soil properties in Hawaii.* Water Resour. Res. 4(2):336-345, illus.
Gross splash was related to a soil erodibility index, bulk density, and infiltration and saturation moisture content; in contrast, maximum splash erosion variation was related to organic matter content as well as to an erodibility index and the bulk density of the soil.

2310. Ziemer, Robert R.
1964. *Summer evapotranspiration trends as related to time following logging of high elevation forest stands in Sierra Nevada.* J. Geophys. Res. 69(4):615-620, illus.
At the period of maximum soil moisture depletion, logged openings one year of age were found to have 6.9 inches more soil moisture per 4-foot soil than did the surrounding forest, which is an expression of the quantity of moisture saved as a result of the logging operation.

2311. Ziemer, Robert R., Norman A. MacGillivray, and Irving Goldberg.
1967. *Measuring moisture near soil surface . . . minor differences due to neutron source type.* U.S. Forest Serv. Res. Note PSW-158, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The variability in surface detection by the four different neutron sources tested may be due to differences in neutron energy or in length of source or in both.

2312. Ziemer, Robert R.
1968. *Soil moisture depletion patterns around scattered trees.* U.S. Forest Serv. Res. Note PSW-166, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Soil moisture measured around an isolated mature sugar pine showed a total moisture depletion of 22.57 inches from the 61-foot radius plot for the 1966 summer depletion season.

2313. Zinke, Paul J.
1959. *The influence of a stand of Pinus coulteri on the soil moisture regime of a large San Dimas lysimeter in southern California.* Int. Union of Geodesy and Geophys. Symp. on Woodlands and Water. Proc. 1959:126-138.
Summer soil moisture loss rates were nearly the same at various depths under a pine cover, but they diminished with depth under a bare surface.

Range Management

2314. Adams, Lowell, Eugene Stefanescu, and David J. Dunaway.
1961. *Gibberellin and thiourea break seed dormancy in California ceanothus.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 178, 4 p., illus. Berkeley, Calif.
Seed dormancy was broken in mountain whitethorn, Lemmons ceanothus, and buckbrush ceanothus by soaking seeds in boiling water (1 min.), 440 p.p.m. gebberellin (13 hrs.), and 3 pct. thiourea (5 min.).

2315. Adams, Lowell.
1962. *Planting depths for seeds of three species of ceanothus.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 194, 3 p. Berkeley, Calif.
An exploratory study suggests that emergence of deerbrush, Lemmons, and wedgeleaf ceanothus may be best when seed is planted at depths of one-half to one inch.

2316. Aigner, Dennis J.
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2317. Ashby, William C., and Henry Hellmers.
1955. *Temperature requirements for germination in relation to wildland seeding.* J. Range Manage. 8(2):80-83.
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2318. Ashby, William C., and Henry Hellmers.
1959. *Flowering and growth responses to photoperiod and temperature for six southern California grasses.* The Botanical Gaz. 120(3):151-157, illus.
Both photoperiod and temperature were found to markedly affect growth and flowering of the annual and perennial grasses studied.

2319. Belshaw, C. M.
1936. *Velezia rigida in the Sierra Nevada foothills.* Madroño 3(7):320.
Describes well established communities in Tuolumne and Eldorado Counties.

2320. Bentley, Jay R.
1941. *Automatic recording of salting and watering habits of cattle.* J. For. 39(10):832-836.
A continuous record can be obtained by mechanical means on the amount of time spent by cattle between salting and watering.

2321. Bentley, Jay R.
1943. *Reseeding trials in Sierra Nevada foothills.* West. Livest. J. 21(49):44-51.
Forage plants are being tested at the San Joaquin Experimental Range in a search for species that can be used to improve California foothill ranges.

2322. Bentley, Jay R., and M. W. Talbot.
1945. *How many head?* West. Livest. J. 23(43):21, 40, 42, 43.
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2323. Bentley, Jay R.
1946. *Forage species tested for more extensive reseeding trails on central California range lands.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 48, 14 p. Berkeley, Calif.
Gives results of preliminary nursery and field trials of more than one-hundred species of forage plants to determine suitability for more extensive field trials.

2324. Bentley, Jay R.
1946. *Range fertilization — one means of improving range forage.* Calif. Cattleman Sept. 1946:6, 24.
Results obtained during fire seasons at the San Joaquin Experimental Range indicate that gypsum and fertilizers containing sulfur stimulate the growth of legumes on many California soils.

2325. Bentley, Jay R., and M. W. Talbot.
1948. *Annual-plant vegetation of the California foothills as related to range management.* Ecology 29(1):72-79.
Describes the California foothill area—its location, climate, and present forage cover—and some considerations in formulating management objectives on these rangelands.

2326. Bentley, Jay R., and M. W. Talbot.
1950. *Why seed brush burns?* In *What we know about brushland management in California.* p. 20-22. Assembled by Milton D. Miller, Agric. Ext. Serv., College of Agric., Univ. of Calif. Sept. 30, 1949. Also appeared in Calif. Cattleman Aug. 1950:10, 11. And in West. Livest. J. 28(64):60, 61, under the title *Seeding burns.*
Recommends program of range improvement involving replacement of slow-growing annual grasses with more productive perennials.

2327. Bentley, Jay R., and M. W. Talbot.
1951. *Efficient use of annual plants on cattle ranges in the California foothills.* USDA Circ. No. 870, 52 p. U.S. Gov. Print. Off., Washington, D.C.
Reports the forage value of several annual plants on the San Joaquin Experimental Range and develops practical guidelines for increasing grazing efficiency.

2328. Bentley, Jay R., and Lisle R. Green.
1954. *Stimulation of native annual clovers through application of sulfur on California foothill range.* J. Range Manage. 7(1):25-30.
The initial stimulation of legumes produces increased yields of grasses and legumes for a few years.

2329. Bentley, Jay R., L. J. Berry, Donald R. Cornelius, and R. M. Love.
1956. *Range species recommended for sowing on cleared brushland in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 111, 10 p., illus. Berkeley, Calif.
Joint recommendations of the Forest Service, the Agricultural Research Service, and the University of California for basic annual and perennial plant mixtures and for alternate species to be sown in the brushland zone.

2330. Bentley, Jay R., and R. F. Buttery.
1957. *Bumper forage crops—it takes more than just high rainfall.* West. Livest. J. 35:152-154.
Average or better herbage production on foothill ranges requires a minimum of 15 to 17 inches of rain well distributed from October to April.

2331. Bentley, Jay R., Lisle R. Green, and K. A. Wagnon.
1958. *Herbage production and grazing capacity on annual-plant range pastures fertilized with sulfur.* J. Range Manage. 11:133-140.
Production was increased approximately 60 percent above unfertilized ranges over a 5-year period, grazing capacity was increased 50 percent.

2332. Bentley, Jay R., and Ralph L. Fenner.
1958. *Soil temperatures during burning related to postfire seedbeds on woodland range.* J. For. 56(10):737-740, illus.
Depth of charring and incineration within the mineral soil proved better criteria than surface appearances for judging soil temperatures during burning and favorable conditions for postfire seeding.

2333. Berg, Arthur R.
1972. *Grass reproduction.* In *The biology and utilization of grasses,* p. 334-347. V. B. Younger and C. M. McKell, ed. Academic Press, Inc., New York.
Describes the reproductive mechanisms of the vegetative plant and the structure that develops from the shoot meristem after floral induction.

2334. Biswell, H. H.
1939. *A change in our California forage plants.* Calif. Cattleman, Sept. 1939:4-5.
The forage composition of California rangelands has changed drastically due to cultivation and introduced species.

2335. Biswell, H. H.
1940. *Subterranean clover growing well at the San Joaquin Experimental Range.* Calif. Wool Grower, 16(39):4-5.
Much breeding work has been done on subterranean clover, an important European and Australian forage plant which is fine feed for sheep because it produces a heavy crop of burs in addition to lush, nutritious, green foliage.

2336. Biswell, H. H., and C. H. Graham.
1956. *Plant counts and seed production on California annual-type ranges.* J. Range Manage. 9(3):116-118.
Describes density, production, type, and mortality rate of the species of plants growing on annual-type foothill ranges.

2337. Bjugstad, Ardell J., Crawford S. Hewlette, and Donald L. Neal.
1970. *Determining forage consumption by direct observation of domestic grazing animals.* U.S. Dep. Agric. Misc. Publ. 1147, p. 101-104.
Grazing animals were observed to determine their forage consumption; the reasons why they desire certain plants at certain times of the grazing season are suggested.

2338. Buttery, R. F.
1956. *Range conditions and trends resulting from winter concentrations of elk in Rocky Mountain National Park, Colorado.* J. Range Manage. 9(3):148.
Reports range conditions and trends in condition observed by the line-intercept and Parker three-step methods on two concentration areas of elk winter range.

2339. Conrad, C. Eugene, and Charles E. Poulton.
1966. *Effect of a wildfire on Idaho fescue and bluebunch wheatgrass.* J. Range Manage. 19(3):137-141.
Finds that Idaho fescue was more susceptible than bluebunch wheatgrass to damage by fire, from a study in northeastern Oregon.

2340. Conrad, C. Eugene, E. J. Woolfolk, and D. A. Duncan.
1966. *Fertilization and management implications on California annual-plant range.* J. Range Manage. 19(1):20-26, illus.
In the first three years of study, sulfur and sulfur-plus-nitrogen fertilizer increased production, especially in terms of herbage yield and grazing capacity; some of the effects these results may have on the costs of grazing cattle are discussed.

2341. Conrad, C. Eugene, and William G. O'Regan.
1973. *Two-stage stratified sampling to estimate herbage yield.* USDA Forest Serv. Res. Note PSW-278, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Two-stage stratified sampling can result in a 15 percent reduction in the variance of the mean weight compared with an equal budget for simple random sampling.

2342. Cornelius, Donald R.
1950. *Reseeding forest ranges.* In *Short course on range improvement,* Hunt Hall Auditorium, Univ. of Calif., Davis. Jan. 31, Feb. 1 and 2, 1950, p. 33-37.
Discusses selection of suitable sites, proper methods for seedbed preparation and for seeding, and use of adapted species.

2343. Cornelius, Donald R.
1950. *Seed production of native grasses under cultivation in eastern Kansas.* Ecol. Monogr. 20:1-29.
Seed production was found to depend on favorable soil moisture, moderate air temperature, and fairly high humidity.

2344. Cornelius, Donald R.
1951. *Relative rating of forage species for reseeding forest ranges in northeastern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 76, 4 p. Berkeley, Calif.
Density and stand vigor ratings for 46 range species in three years of testing in the Great Basin sagebrush zone.

2345. Cornelius, Donald R.
1952. *Ecological aspects of reseeding and fertilization in range improvement.* In *Proceedings of Fourth Annual California Weed Conference,* San Luis Obispo, Calif. Jan. 22-24, 1952:37-42.
Discusses the influence of competition and other ecological factors on the success of range improvement practices.

2346. Cornelius, Donald R., and M. W. Talbot.
1955. *Rangeland improvement through seeding and weed control on east slope Sierra Nevada and on southern Cascade Mountains.* U.S. Dep. Agric. Handb. 88, 51 p., illus.
Describes range improvement measures for sagebrush, dry grassland sites, mountain meadows, pine forest type, and aspen and red fir types.

2347. Countryman, Clive M., and Donald R. Cornelius.
1957. *Some effects of fire on a perennial range type.* J. Range Manage. 10(1):39-41.
Perennial grasses and bitterbrush were decidedly reduced on the burned plots, largely because of change in microclimate and closer grazing.

2348. Currie, Pat O., Meredith J. Morris, and Donald L. Neal.
1973. *Uses and capabilities of electronic capacitance instruments for estimating herbage production. Part II: Sown ranges.* J. Br. Grassl. Soc. 28:155-160, illus.
The electronic capacitance meter can be used satisfactorily for obtaining yield estimates of seeded ranges for routine herbage production estimates and treatment comparisons on experimental pastures.

2349. Duncan, Don A.
1965. *Grazing management on annual-plant rangeland.* Stockman's Weekly 6(34):1, 4, 5.
Outlines grazing management studies underway at the San Joaquin Experimental Range on both fertilized and natural rangeland and summarizes main results.

2350. Duncan, Don A., and Jack N. Reppert.
1960. *A record drought in the foothills.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 46, 6 p., illus. Berkeley, Calif.
A new low in rainfall at the San Joaquin Experimental Range during 1959 reduced range herbage production from 1600 to less than 700 pounds per acre, and the length of adequate green grazing season from 18 to 11 weeks.

2351. Duncan, Don A., and Jack N. Reppert.
1961. *Even dry—fertilized ranges produce more meat.* West. Livest. J. 39(35):15.
Despite extreme drought in the 1959 growing season sulfur fertilization caused moderate increases in cattle weight gains and nitrogen-plus-sulfur fertilization doubled the amount of animal gain and more than tripled herbage yield and animal days of grazing per acre.

2352. Duncan, Don A., and Stanley L. Anderson.
1961. *Portable feeders for range grazing studies.* J. Range Manage. 14(3):159-160, illus.
Describes two types of portable feeders, one commercial and one homemade, that have proved satisfactory for different needs in range grazing studies.

2353. Duncan, Don A., and Stanley L. Anderson.
1963. *Chronicle of a great feed year in the Golden State.* West. Livest. J. 41(49):3.
Extension of favorable rains in late April 1963 produced unusually heavy herbage yields and doubled grazing capacity on foothill ranges.

2354. Duncan, Don A., and Jack N. Reppert.
1966. *Helicopter fertilizing of foothill range.* U.S. Forest Serv. Res. Note PSW-108, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports good distribution and rate of application of sulfur-fertilizer on California annual-plant range in 1960 and 1963.

2355. Duncan, Don A.
1967. *How range fertilization can increase forage and beef yields.* Memorias de la Session Technica, Chihuahua, Mex., X Anniv. Centro. Nac. de Invest. Pecuarias, SAG, 1-6.
Over the years 60 pounds of sulfur per acre added every three years has resulted in an average annual increase of about 50 percent for both herbage and beef yield.

2356. Duncan, Don A., and Lynn O. Hylton, Jr.
1970. *Effects of fertilization on quality of range forage.* U.S. Dep. Agric. Misc. Publ. 1147, p. 57-61.
Reviews pertinent literature and current studies on the effects of inorganic fertilizers on the quality of range and pasture forage.

2357. Duncan, Don A., and Merton J. Reed.
1973. *Yearlong tops seasonal grazing in extended rangeland study.* West. Livestock J., Mountain, Plains and Southwest Edition 51(21):32, 48, illus. [Pacific Slope Ed. p. 32-33]
Weight responses of both cows and calves were considerably and consistently better on ranges grazed yearlong than under seasonal grazing systems in an 8-year study at the San Joaquin Experimental Range.

2358. Duncan, Don A., and Robert G. Woodmansee.
1975. *Forecasting forage yield from precipitation in California's annual rangeland.* J. Range Manage. 28(4):327-329.
A study at the San Joaquin Experimental Range showed poor correlation between forage yield and monthly or annual precipitation.

2359. Duncan, Don A.
1975. *The San Joaquin site of the grassland biome: its relation to annual grassland ecosystem synthesis.* In *The California Annual Grassland Ecosystem: Symposium Proceedings, Anaheim, Calif., Jan. 30, 1975.* p. 9-15, Inst. Ecol., Univ. Calif., Davis.
Reports preliminary results from analyses of abiotic, producer, consumer, and decomposer components of the San Joaquin ecosystem.

2360. Fitch, Henry S., and Jay R. Bentley.
1949. *Use of California annual-plant forage by range rodents.* Ecology 30(3):306-321.
Reports on the potential destructiveness of three range rodents as determined in enclosures at the San Joaquin Experimental Range.

2361. Gaylord, Vernon J., and Stanley E. Westfall.
1971. *Wedgeleaf ceanothus canopy does not affect total herbage yield.* USDA Forest Serv. Res. Note PSW-253, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Total herbage yield was not significantly influenced by the canopy effect of wedgeleaf ceanothus.

2362. Gordon, Aaron, and Arthur W. Sampson.
1939. *Composition of common California foothill plants as a factor in range management.* Berkeley Calif. Agric. Exp. Stn. Bull. 627, 95 p.
Reports a study of chemical characteristics of certain foothill range plants yielding information on plant succession, classification, and economic value in order to perfect more dependable methods for estimating the carrying capacity of the range.

2363. Green, Lisle R., and Jay R. Bentley.
1954. *Some costs and returns from applying sulfur fertilizers on rangeland.* Calif. Cattleman May 1954:8-9. West. Pasture J. 5(2):20-21.
Methods of sulfur fertilization at the San Joaquin Experimental Range are described and costs and returns are compared for three common carriers of sulfur: soil sulfur, gypsum, and single superphosphate.

2364. Green, Lisle R., and Donald R. Cornelius.
1957. *Pampasgrass in the Sierra foothills.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 132, 7 p., illus. Berkeley, Calif.
Reports on the propagation, survival, vigor, and grazing value for this grass as determined during a 7-year period at the San Joaquin Experimental Range.

2365. Green, Lisle R., and Donald R. Cornelius.
1957. *Seeding and grazing trials of stipa on foothill ranges.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note No. 128, 9 p., illus. Berkeley, Calif.
Reports stand establishment from seeding of purple and nodding stipa and their maintenance under grazing and fertilization.

2366. Green, Lisle R., and Charles A. Graham.
1958. *Annual legumes on granitic soil in the central Sierra foothills.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 24, 11 p. Berkeley, Calif.
Introduced species were successfully established only on bottomland soils, fertilization of native clovers offers the best choice for increasing legumes.

2367. Green, Lisle R., K. A. Wagnon, and Jay R. Bentley.
1958. *Diet and grazing habits of steers on foothill range fertilized with sulfur.* J. Range Manage. 11:221-227, illus.
Beneficial changes in species composition and chemical content in turn influenced diet and grazing habits of steers.

2368. Green, Lisle R.
1959. *Some effects of sulfur fertilization on nodulation and growth of annual range legumes.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 156, 7 p. Berkeley, Calif.
Reports increase in number and size of root nodules on range legumes as a result of sulfur fertilization.

2369. Hellmers, Henry, and William C. Ashby.
1958. *Growth of native and exotic plants under controlled temperature and in the San Gabriel Mountains, California.* Ecology 39(3):416-428.
Describes a study to determine the species most adapted for survival and growth in the San Gabriel Mountains.

2370. Hormay, August L.
1938. *Report on the cooperative Western range survey in Madera County, California.* 36 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes some of the range management problems confronting Madera County stockmen and recommends range practices for improvement.

2371. Hormay, August L.
1938. *Report on the cooperative Western range survey in Merced County, California.* 30 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Discusses problems in past use, and summarizes some of the existing information on the range lands with the view that it may aid in defining and solving some of the more important problems connected with the maintenance of the range resources.

2372. Hormay, August L.
1938. *Report on the cooperative Western range survey in San Benito County, California.* 56 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes the extent and condition of the range resources in San Benito County and points out some of the more important problems connected with their use.

2373. Hormay, August L.
1940. *The effect of logging on forage.* Chron. Bot. 6(1):6-7.
Finds that grazing capacity is reduced for a year or two following logging, as tree reproduction reoccupies the ground the grazing capacity reaches a maximum and then slowly takes a downward trend.

2374. Hormay, August L.
1940. *Palatabilities of foothill range plants for cattle.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 25, 4 p. Berkeley, Calif.
Lists annual type plants and their percent palatibility in order to facilitate the completion of the Western range survey in San Benito County.

2375. Hormay, August L., and Adelbert Fausett.
1942. *Standards for judging the degree of forage utilization on California annual-type ranges.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 21, 13 p. Berkeley, Calif.
Presents a series of photographs of different range conditions and details on how to use them as standards for judging degree of utilization.

2376. Hormay, August L.
1943. *Bitterbrush in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 34, 13 p. Berkeley, Calif.
Describes *Purshia tridentata* and discusses its distribution, forage value, enemies, growth pattern, reproduction, and methods used in planting.

2377. Hormay, August L.
1943. *A method of estimating grazing use of bitterbrush.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 35, 4 p. Berkeley, Calif.
Presents a method used to measure grazing of *Purshia tridentata* which consists of estimating the amount of current twig growth grazed on marked bushes.

2378. Hormay, August L.
1943. *Observations on species composition in northeastern California meadows as influenced by moisture supply.* 6 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Reports on how changes in moisture conditions affect the composition of vegetation in meadows and makes suggestions for management beneficial to waterfowl and livestock grazing.

2379. Hormay, August L.
1944. *Moderate grazing pays on California annual-type ranges.* U.S. Dep. Agric. Leafl. No. 239, 8 p. Gov. Print. Off., Washington, D.C.
Points to the virtues of moderate grazing for sustaining high level production on annual type ranges—new plant growth will begin 2 or 3 weeks earlier than those grazed closely and will result in a relatively thick, even, vigorous cover of forage plants.

2380. Hormay, August L.
1947. *Forest grazing in California.* Soc. Am. For. Proc. Annu. Meet. Dec. 17-20, 1947:286-296.
Describes the cover types, topography, and climate of forest ranges and how they furnish a small but important portion of the forage needed by the beef cattle and sheep industries to round out their yearlong operations.

2381. Hormay, August L.
1949. *Getting better records of vegetation changes with the line interception method.* J. Range Manage. 2(2):67-69.
Points out a few ways in which the line intercept method can be used to obtain satisfactory records of density and composition and to determine yield of range vegetation.

2382. Hormay, August L., and Jay R. Bentley.
1949. *The land-variability factor in cattle-grazing experiments.* In *Proceedings of the Berkeley Symposium on Mathematical Statistics and Probability,* p. 465-467. Univ. of Calif. Press, Berkeley, Calif.
Close study of an experiment to determine the effect of forage-producing site on intensity of grazing, cattle weights, and forage changes points to the possibility of measuring range variations in pastures and using the information in interpreting the results of treatments.

2383. Hormay, August L.
1956. *How livestock grazing habits and growth requirements of range plants determine sound grazing management.* J. Range Manage. 9(6):161-164, illus.
Studies on mountain ranges in the pine timber and grassland of northeastern California show that selective grazing by livestock is a main cause of range deterioration.

2384. Hormay, August L., and Anthony B. Evanko.
1958. *Rest-rotation grazing—a management system for bunchgrass ranges.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 27, 14 p., illus. Berkeley, Calif.
Basic principles and practical steps for putting into operation a grazing system geared to improving and maintaining high forage and livestock production.

2385. Hormay, August L.
1960. *Moderate grazing pays on California annual-type ranges.* U.S. Dep. Agric. Leafl. 239 (rev.), 5 p., illus.
Defines moderate grazing, describes its beneficial effects on forage and livestock production, points out the

relationship between range utilization and range production capacity, and explains how to judge the appearance of moderately grazed range.

2386. Hormay, August L., and M. W. Talbot.
1961. *Rest rotation grazing . . . a new management system for perennial bunchgrass ranges.* U.S. Dep. Agric. Prod. Res. Rep. 51, 43 p.
Reports research which provided the basis for a grazing system designed to improve or maintain perennial bunchgrass ranges.

2387. Hormay, August L., Fred J. Alberico, and P. B. Lord.
1962. *Experiences with 2,4-D spraying on the Lassen National Forest.* J. Range Manage. 15(6):325-328, illus.
Results indicate a particular need for information on susceptibility of range plants to spraying at different growth stages.

2388. Hormay, August L.
1970. *Principles of rest-rotation grazing and multiple-use land management.* Div. Range Manage., Forest Serv. USDA Forest Serv. Training Text 4(2200), 26 p. illus.
Discusses grazing management in relation to application on 728 million acres of wildland in the Western United States.

2389. Hubbard, Richard L.
1956. *Bitterbrush seedlings destroyed by cutworms and wireworms.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 114, 2 p. Berkeley, Calif.
Cutworm and wireworm damage was found a threat to bitterbrush reseeding in northeastern California.

2390. Hubbard, Richard L.
1956. *Effect of depth of planting on the emergence of bitterbrush seedlings.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 113, 6 p., illus. Berkeley, Calif.
Two inches seems about the maximum depth from which bitterbrush seedlings can be expected to emerge with the best emergence from seed planted 0.5 to 1.5 inches deep, depending on soil-moisture conditions.

2391. Hubbard, Richard L.
1956. *The effects of plant competition upon the growth and survival of bitterbush seedlings.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 109, 9 p., illus. Berkeley, Calif.
Seedbed preparation, alone and with subsequent weeding, increased seedling growth of bitterbrush and reduced mortality.

2392. Hubbard, Richard L.
1957. *The effects of plant competition upon the growth and survival of bitterbrush seedlings.* J. Range Manage. 10(3):135-137.
See item 2391 above.

2393. Hubbard, Richard L., and B. O. Pearson.
1958. *Germination of thiourea treated bitterbrush seed in the field.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 138, 6 p. Berkeley, Calif.
Seed dormancy was successfully broken without damage to seedling emergence or survival.

2394. Hubbard, Richard L.
1958. *Hot water bath and thiourea break dormancy of wedgeleaf ceanothus seed.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 143, 4 p. Berkeley, Calif.
Hot water followed by soaking in 3 percent thiourea for 13 hours gave 31 percent germination.

2395. Hubbard, Richard L., and David Dunaway.
1958. *Variation in leader length of bitterbrush.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 145, 4 p. Berkeley, Calif.
For five bushes studied, an unrestricted random sample of 19 to 39 leaders was required for a reliable estimate of average leader length.

2396. Hubbard, Richard L., Eamor C. Nord, and L. L. Brown.
1959. *Bitterbrush reseeding—a tool for the game range manager.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 39, 14 p., illus. Berkeley, Calif.
This is a guide to successful planting of bitterbrush on western deer ranges.

2397. Hubbard, Richard L., H. Reed Sanderson, and David Dunaway.
1960. *Herbage production and carrying capacity of bitterbrush.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 157, 6 p., illus. Berkeley, Calif.
Reports weight of herbage produced by five mature bitterbrush plants and relates production to deer needs.

2398. Hubbard, Richard L., and H. Reed Sanderson.
1961. *Grass reduces bitterbrush production.* Calif. Fish and Game 47(4):391-398, illus.
Removing perennial grass and weeds beneath bitterbrush nearly doubled the number and length of bitterbrush leaders.

2399. Hubbard, Richard L., and Sturgis McKeever.
1961. *Meadow mouse girdling—another cause of death*

of reseeded bitterbrush plants. Ecology 42(1):198, illus.
On a reseeded bitterbrush area, mice killed 5 percent of the plants and damaged 15 percent.

2400. Hubbard, Richard L., and H. Reed Sanderson.
1961. *When to plant bitterbrush—spring or fall?* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 64, 21 p., illus. Berkeley, Calif.
For success in planting bitterbrush, the soil at planting depth must remain moist during germination and emergence.

2401. Hubbard, Richard L., Pinhaus Zusman, and H. Reed Sanderson.
1962. *Bitterbrush stocking and minimum spacing with crested wheatgrass.* Calif. Fish and Game 48(3):203-208, illus.
Individual bitterbrush plants on a 1953 seeding began dying in 1959, apparently from lack of moisture with plants within 2 feet of crested wheatgrass seriously damaged.

2402. Hubbard, Richard L.
1964. *A guide to bitterbrush seeding in California.* 30 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A 5-step prescription for seeding is explained and uses of the plant in rehabilitation of big-game ranges is given.

2403. Hubbard, Richard L.
1974. *Castanopsis* (D. Don) Spach. Chinkapin. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 276-277, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

2404. Hubbard, Richard L.
1974. *Rhamnus* L. Buckthorn. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 704-708, illus.
See item 2403 above.

2405. Hutchinson, C. B., and E. I. Kotok.
1942. *The San Joaquin Experimental Range.* Calif. Agric. Exp. Stn. Bull. 663, 145 p. Berkeley, Calif.
Contains a collection of papers by various authors describing the Experimental Range, wildlife relations, ranch organization and management, forage crop and herd management.

2406. Hyder, D. N., C. Eugene Conrad, and others.
1963. *Frequency sampling in sagebrush-bunchgrass vegetation.* Ecology 44(4):740-746, illus.
Reports on efficient quadrat sizes and allocations of sampling units for frequency sampling, and reviews pertinent theoretical considerations.

2407. Hylton, Lynn O., and Albert Ulrich.
1968. *Critical nitrate-N concentrations for growth of two strains of Idaho fescue.* J. Range Manage. 21(5):321-325, illus.
Nitrate-N in shoots should be above 500 ppm, dry basis, during active vegetative growth if maximum forage production is desirable.

2408. Hylton, Lynn O., Donald R. Cornelius, and Albert Ulrich.
1968. *Sulfur needs of Spanish clover and the relation of sulfur and other nutrients as diagnosed by plant analysis.* J. Range Manage. 21(3):129-135.
Top growth was affected more than root growth by changes in sulfur supply and protein synthesis in the shoots was little affected by sulfur deficiency.

2409. Hylton, Lynn O., and Albert Ulrich.
1969. *Comparative growth stages and plant parts for critical nitrate-N concentration of squirreltail.* J. Range Manage. 22(3):188-192, illus.
The critical nitrate-N concentration was not appreciably affected by plant maturity when recently-matured blades rather than entire shoots were analyzed for nitrate-N.

2410. Hylton, Lynn O., Donald R. Cornelius, and Albert Ulrich.
1970. *Nitrogen nutrition and growth relations of tall and intermediate wheatgrasses.* Agron. J. 62:353-356.
In a common and favorable environment, intermediate wheatgrass grew faster than tall wheatgrass.

2411. Hylton, Lynn O.
1974. *Penstemon* Mitch. Penstemon. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 574-575, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

2412. Liacos, Leonidas G., and Eamor C. Nord.
1961. *Curlleaf cercocarpus seed dormancy yields to acid and thiourea.* J. Range Manage. 14(6):317-320, illus.
Curlleaf cercocarpus seed treated for 5 minutes in concentrated sulfuric acid and 4 hours in 3 percent thiourea yielded 76 percent germination compared to 14 percent germination for untreated seed.

2413. McConnen, Richard J., C. B. McCorkel, and D. D. Caton.

1963. *Feed-livestock relationships, a model for analyzing management decisions.* Agric. Econ. Res. 15(2):41-48.
Livestock production is considered as a three-stage production process, (a) a feed procurement, (b) feed consumption, and (c) feed conversion, and a general economic model is developed.

2414. McConnen, Richard J.
1965. *Relation between the pattern of use and the future output from a flow resource.* J. Farm Econ. 47(2):311-323.
Examines the results from a grazing intensity study conducted in the Northern Great Plains to determine the impact of human action on the future rates of flow from flow resources.

2415. McKell, Cyrus M., Charles A. Graham, and Alma M. Wilson.
1960. *Benefits of fertilizing annual range in a dry year.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 172, 9 p., illus. Berkeley, Calif.
Range fertilization resulted in earlier range readiness, increased herbage production, and increased protein content of herbage, during droughty 1959, but at somewhat reduced level compared to more favorable years.

2416. Neal, Donald L., and Lee R. Neal.
1965. *A new electronic meter for measuring herbage yield.* U.S. Forest Serv. Res. Note PSW-56, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A new instrument, called the Hetrodyne Vegetation Meter, which measures herbage yield and utilization, was built and tested.

2417. Neal, Donald L., Richard L. Hubbard, and C. Eugene Conrad.
1969. *A magnetic point frame.* J. Range Manage. 22(3):202-203, illus.
The point frame has been improved by using pot magnets as brakes for pins.

2418. Neal, Donald L., and Jerry L. Neal.
1973. *Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part I. History and development.* J. Br. Grassl. Soc. 28(2):81-89, illus.
Describes briefly the significant steps in the development of electronic capacitance instruments for estimating weight of vegetation.

2419. Neal, Donald L.
1974. *Carpenteria californica* Torr. Carpenteria. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 265, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

2420. Neal, Donald L.
1974. *Dendromecon rigida* Benth. Stiff Bushpoppy. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 372, illus.
See item 2419 above.

2421. Neal, Donald L., and H. Reed Sanderson.
1975. *Thiourea solution temperature and bitterbrush germination and seedling growth.* J. Range Manage. 28(5):421-423, illus.
Normal germination and seedling growth resulted at temperatures between 60° F. and 140° F.; below 60° F. there was a slight reduction in germination, but seedling growth was normal.

2422. Nord, Eamor C., and G. E. Whitacre.
1957. *Germination of fourwing saltbush seed improved by scarification and grading.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 125, 5 p. Berkeley, Calif.
Germination success is inversely related to seed size with moderate scarification hastening the rate of germination and heavy scarification increasing total germination.

2423. Nord, Eamor C.
1958. *Rice hulls improve drilling bitterbrush seed.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 134, 5 p. Berkeley, Calif.
Gives operating hints and seeding chart for sowing with rice hulls for uniform distribution with standard fluted-feed grain drill.

2424. Nord, Eamor C.
1959. *Bitterbrush plants can be propagated from stem cuttings.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 149, 4 p., illus. Berkeley, Calif.
Describes method of making *Purshia tridentata* stem cuttings and reports rooting success in one trial.

2425. Nord, Eamor C.
1963. *Bitterbrush seed harvesting: when, where, and how.* J. Range Manage. 16:258-261, illus.
A seed ripening prediction chart is given to enable collectors to schedule bitterbrush seed harvesting throughout California, and several sites possessing good seed production potential are identified.

2426. Nord, Eamor C., Edward R. Schneegas, and Hatch Graham.

1967. *Bitterbrush seed collecting—by machine or by hand.* J. Range Manage. 20(2):96-99, illus.
Collecting seed by hand using Forest Service crews was the most economical method; collecting with the experimental browse seed harvester was the most expensive; and purchase from private collectors was intermediate in cost.

2427. Nord, Eamor C., and Joe R. Goodin.
1970. *Rooting cuttings of shrub species for plantings in California wildlands.* USDA Forest Serv. Res. Note PSW-213, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Fourwing, Gardner's Nuttall's, and allscale saltbushes and creeping sage rooted successfully under intermittent mist from green tip and ripewood stem cuttings taken in spring and fall.

2428. Nord, Eamor C., Patrick F. Hartless, and W. Dennis Nettleton.
1971. *Effects of several factors on saltbush establishment in California.* J. Range Manage. 24(3):216-223, illus.
Emergence and survival were significantly higher in seedlings grown at the ½-inch depth than in the 1-inch depth.

2429. Nord, Eamor C., Louis E. Gunter, and Stuart A. Graham, Jr.
1971. *Gibberellic acid breaks dormancy and hastens germination of creeping sage.* USDA Forest Serv. Res. Note PSW-259, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The most effective, practical, and lasting treatment tested was by a gibberellic acid soak under constant agitation at 500 ppm for 4 hours.

2430. Nord, Eamor C.
1956. *Quick testing bitterbrush seed viability.* J. Range Manage. 9(4):193-194, illus.
Describes a four-step procedure for determining viability of bitterbrush seed.

2431. O'Regan, William G., and C. Eugene Conrad.
1975. *Number of pins in two-stage stratified sampling for estimating herbage yield.* USDA Forest Serv. Res. Note PSW-300, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a procedure to compute the effect of the number of pins in a pin frame on the variance of estimated herbage yield.

2432. Pearson, B. O.
1957. *Bitterbrush seed dormancy broken with thiourea.* J. Range Manage. 10(1):41-42.
Highly dormant bitterbrush seed germinated 85 percent after soaking for 3 to 5 minutes in a 3 percent solution of thiourea.

2433. Rader, Lynn.
1961. *Economic evaluation of range improvement and management practices.* Am. Soc. Range Manage. 14th Annu. Meet., Jan. 31-Feb. 3, 1961:60-61.
Despite technical progress in range management, little has been done to determine the economic feasibility of recommended practices.

2434. Rader, Lynn.
1961. *Grazing management pays on perennial grass range during drought.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 179, 2 p. Berkeley, Calif.
Two consecutive drought years reduced livestock gains and length of grazing season on many grazing units, but under rest-rotation management cattle were carried for the full grazing season with normal weight gains.

2435. Rader, Lynn, and Raymond D. Ratliff.
1962. *A new idea in point frames.* J. Range Manage. 15(3):182-183, illus.
New version of the point frame employs notches rather than holes to guide the pins and requires one pin rather than a set of ten.

2436. Ratliff, Raymond D., and Lynn Rader.
1962. *Drought hurts less with rest-rotation management.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 196, 4 p., illus. Berkeley, Calif.
Despite a third successive year of drought, forage production on a practical scale trial of rest-rotation grazing management was adequate for normal grazing use.

2437. Ratliff, Raymond D.
1962. *Preferential grazing continues under rest-rotation management.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 206, 6 p., illus. Berkeley, Calif.
Even with much attention to livestock distribution, preferential grazing still occurs under rest-rotation management; however, this management provides needed rest for preferred areas and forces cattle to use some areas they otherwise might not graze.

2438. Ratliff, Raymond D., and Jack N. Reppert.
1965. *Locating pairs of comparable study areas . . . new system developed.* U.S. Forest Serv. Res. Note PSW-129, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a system for locating pairs of "comparable" areas on which to establish study plots.

2439. Ratliff, Raymond D., and Stanley E. Westfall.
1971. *Non-grazing and gophers lower bulk density and acidity in annual-plant soil.* USDA Forest Serv. Res. Note PSW-254, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A range with this soil, after 34 years of non-grazing use, had a lower surface bulk density and lower acidity than an adjacent grazed range.

2440. Ratliff, Raymond D.
1972. *Livestock grazing not detrimental to meadow wildflowers.* USDA Forest Serv. Res. Note PSW-270, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Rest-rotation grazing produced desirable results compared to free-choice grazing, but it did result in a reduction in flower-producing forbs.

2441. Ratliff, Raymond D., Stanley E. Westfall, and Richard J. McConnen.
1972. *More California-poppy in stubble field than in old field.* USDA Forest Serv. Res. Note PSW-271, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A site disturbance which produced a harsh microclimate or reduced competition or both will probably favor California-poppy.

2442. Ratliff, Raymond D., Jack N. Reppert, and Richard J. McConnen.
1972. *Rest-rotation grazing at Harvey Valley—range health, cattle gains, costs.* USDA Forest Serv. Res. Paper PSW-77, 24 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Compares short-term costs to returns and evaluates the ecological benefits and cattle weight gains from rest-rotation grazing in northeastern California.

2443. Ratliff, Raymond D.
1973. *Shorthair meadows in the high Sierra Nevada . . . an hypothesis of their development.* USDA Forest Serv. Res. Note PSW-281, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Proposes an hypothesis that can help to understand the shorthair meadows and in deciding on management needed to restore damaged sites.

2444. Ratliff, Raymond D., and Jack N. Reppert.
1974. *Vigor of Idaho fescue grazed under rest-rotation and continuous grazing.* J. Range Manage. 27(6):447-449.
Vigor was maintained at a higher level over the 5-year period with rest-rotation grazing, as indicated by vegetative shoot lengths and flower stalk numbers.

2445. Ratliff, Raymond D., and Richard L. Hubbard.
1975. *Clipping affects flowering of California-poppy at two growth stages.* USDA Forest Serv. Res. Note PSW-303, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Through the early reproductive stage, a single clipping had little effect, but clipping at either the start or the peak of vernal flowering reduced the display of spring flowers.

2446. Reed, Merton J., and Ronald A. Peterson.
1961. *Vegetation, soil, and cattle responses to grazing on northern plains range.* U.S. Dep. Agric. Tech. Bull. 1252, 79 p., illus.
Reports a 14-year study of responses to different intensities of experimental grazing, and includes recommendations for stocking summer and winter ranges, for judging correct herbage removal, and for checking range condition.

2447. Reed, Merton J., and Jon M. Skovlin.
1963. *Estimating grazing values for layout and calibration of experimental ranges.* U.S. Dep. Agric. Misc. Publ. 940, 142-148, illus.
The more common methods for estimating grazing values are discussed in the light of current knowledge, recommendations are made, and research needs are pointed out.

2448. Reppert, Jack N., and Lisle R. Green.
1958. *Annotated bibliography of publications from the San Joaquin Experimental Range.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 27, 32 p. Berkeley, Calif.
Provides brief content descriptions of 135 publications dealing with range management, livestock production, zoological, and other aspects of the cooperative research program since establishment in 1934.

2449. Reppert, Jack N.
1960. *Forage preference and grazing habits of cattle at the Eastern Colorado Range Station.* J. Range Manage. 13:58-65.
Enumerates native forage species and parts of these species which were selected and consumed by cattle grazing sandhill ranges.

2450. Reppert, Jack N., and E. J. Woolfolk.
1960. *Research at the San Joaquin Experimental Range.* 11 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A brief description of the San Joaquin Experimental Range, and its past and present research programs.

2347. Countryman, Clive M., and Donald R. Cornelius.
1957. *Some effects of fire on a perennial range type.* J. Range Manage. 10(1):39-41.
Perennial grasses and bitterbrush were decidedly reduced on the burned plots, largely because of change in microclimate and closer grazing.

2348. Currie, Pat O., Meredith J. Morris, and Donald L. Neal.
1973. *Uses and capabilities of electronic capacitance instruments for estimating herbage production. Part II: Sown ranges.* J. Br. Grassl. Soc. 28:155-160, illus.
The electronic capacitance meter can be used satisfactorily for obtaining yield estimates of seeded ranges for routine herbage production estimates and treatment comparisons on experimental pastures.

2349. Duncan, Don A.
1965. *Grazing management on annual-plant rangeland.* Stockman's Weekly 6(34):1, 4, 5.
Outlines grazing management studies underway at the San Joaquin Experimental Range on both fertilized and natural rangeland and summarizes main results.

2350. Duncan, Don A., and Jack N. Reppert.
1960. *A record drought in the foothills.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 46, 6 p., illus. Berkeley, Calif.
A new low in rainfall at the San Joaquin Experimental Range during 1959 reduced range herbage production from 1600 to less than 700 pounds per acre, and the length of adequate green grazing season from 18 to 11 weeks.

2351. Duncan, Don A., and Jack N. Reppert.
1961. *Even dry—fertilized ranges produce more meat.* West. Livest. J. 39(35):15.
Despite extreme drought in the 1959 growing season sulfur fertilization caused moderate increases in cattle weight gains and nitrogen-plus-sulfur fertilization doubled the amount of animal gain and more than tripled herbage yield and animal days of grazing per acre.

2352. Duncan, Don A., and Stanley L. Anderson.
1961. *Portable feeders for range grazing studies.* J. Range Manage. 14(3):159-160, illus.
Describes two types of portable feeders, one commercial and one homemade, that have proved satisfactory for different needs in range grazing studies.

2353. Duncan, Don A., and Stanley L. Anderson.
1963. *Chronicle of a great feed year in the Golden State.* West. Livest. J. 41(49):3.
Extension of favorable rains in late April 1963 produced unusually heavy herbage yields and doubled grazing capacity on foothill ranges.

2354. Duncan, Don A., and Jack N. Reppert.
1966. *Helicopter fertilizing of foothill range.* U.S. Forest Serv. Res. Note PSW-108, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports good distribution and rate of application of sulfur-fertilizer on California annual-plant range in 1960 and 1963.

2355. Duncan, Don A.
1967. *How range fertilization can increase forage and beef yields.* Memorias de la Session Technica, Chihuahua, Mex., X Anniv. Centro. Nac. de Invest. Pecuarias, SAG, 1-6.
Over the years 60 pounds of sulfur per acre added every three years has resulted in an average annual increase of about 50 percent for both herbage and beef yield.

2356. Duncan, Don A., and Lynn O. Hylton, Jr.
1970. *Effects of fertilization on quality of range forage.* U.S. Dep. Agric. Misc. Publ. 1147, p. 57-61.
Reviews pertinent literature and current studies on the effects of inorganic fertilizers on the quality of range and pasture forage.

2357. Duncan, Don A., and Merton J. Reed.
1973. *Yearlong tops seasonal grazing in extended rangeland study.* West. Livestock J., Mountain, Plains and Southwest Edition 51(21):32, 48, illus. [Pacific Slope Ed. p. 32-33]
Weight responses of both cows and calves were considerably and consistently better on ranges grazed yearlong than under seasonal grazing systems in an 8-year study at the San Joaquin Experimental Range.

2358. Duncan, Don A., and Robert G. Woodmansee.
1975. *Forecasting forage yield from precipitation in California's annual rangeland.* J. Range Manage. 28(4):327-329.
A study at the San Joaquin Experimental Range showed poor correlation between forage yield and monthly or annual precipitation.

2359. Duncan, Don A.
1975. *The San Joaquin site of the grassland biome: its relation to annual grassland ecosystem synthesis.* In *The California Annual Grassland Ecosystem: Symposium Proceedings, Anaheim, Calif., Jan. 30, 1975.* p. 9-15, Inst. Ecol., Univ. Calif., Davis.
Reports preliminary results from analyses of abiotic, producer, consumer, and decomposer components of the San Joaquin ecosystem.

2360. Fitch, Henry S., and Jay R. Bentley.
1949. *Use of California annual-plant forage by range rodents.* Ecology 30(3):306-321.
Reports on the potential destructiveness of three range rodents as determined in enclosures at the San Joaquin Experimental Range.

2361. Gaylord, Vernon J., and Stanley E. Westfall.
1971. *Wedgeleaf ceanothus canopy does not affect total herbage yield.* USDA Forest Serv. Res. Note PSW-253, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Total herbage yield was not significantly influenced by the canopy effect of wedgeleaf ceanothus.

2362. Gordon, Aaron, and Arthur W. Sampson.
1939. *Composition of common California foothill plants as a factor in range management.* Berkeley Calif. Agric. Exp. Stn. Bull. 627, 95 p.
Reports a study of chemical characteristics of certain foothill range plants yielding information on plant succession, classification, and economic value in order to perfect more dependable methods for estimating the carrying capacity of the range.

2363. Green, Lisle R., and Jay R. Bentley.
1954. *Some costs and returns from applying sulfur fertilizers on rangeland.* Calif. Cattleman May 1954:8-9. West. Pasture J. 5(2):20-21.
Methods of sulfur fertilization at the San Joaquin Experimental Range are described and costs and returns are compared for three common carriers of sulfur: soil sulfur, gypsum, and single superphosphate.

2364. Green, Lisle R., and Donald R. Cornelius.
1957. *Pampasgrass in the Sierra foothills.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 132, 7 p., illus. Berkeley, Calif.
Reports on the propagation, survival, vigor, and grazing value for this grass as determined during a 7-year period at the San Joaquin Experimental Range.

2365. Green, Lisle R., and Donald R. Cornelius.
1957. *Seeding and grazing trials of stipa on foothill ranges.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note No. 128, 9 p., illus. Berkeley, Calif.
Reports stand establishment from seeding of purple and nodding stipa and their maintenance under grazing and fertilization.

2366. Green, Lisle R., and Charles A. Graham.
1958. *Annual legumes on granitic soil in the central Sierra foothills.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 24, 11 p. Berkeley, Calif.
Introduced species were successfully established only on bottomland soils, fertilization of native clovers offers the best choice for increasing legumes.

2367. Green, Lisle R., K. A. Wagnon, and Jay R. Bentley.
1958. *Diet and grazing habits of steers on foothill range fertilized with sulfur.* J. Range Manage. 11:221-227, illus.
Beneficial changes in species composition and chemical content in turn influenced diet and grazing habits of steers.

2368. Green, Lisle R.
1959. *Some effects of sulfur fertilization on nodulation and growth of annual range legumes.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 156, 7 p. Berkeley, Calif.
Reports increase in number and size of root nodules on range legumes as a result of sulfur fertilization.

2369. Hellmers, Henry, and William C. Ashby.
1958. *Growth of native and exotic plants under controlled temperature and in the San Gabriel Mountains, California.* Ecology 39(3):416-428.
Describes a study to determine the species most adapted for survival and growth in the San Gabriel Mountains.

2370. Hormay, August L.
1938. *Report on the cooperative Western range survey in Madera County, California.* 36 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Summarizes some of the range management problems confronting Madera County stockmen and recommends range practices for improvement.

2371. Hormay, August L.
1938. *Report on the cooperative Western range survey in Merced County, California.* 30 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Discusses problems in past use, and summarizes some of the existing information on the range lands with the view that it may aid in defining and solving some of the more important problems connected with the maintenance of the range resources.

2372. Hormay, August L.
1938. *Report on the cooperative Western range survey in San Benito County, California.* 56 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Describes the extent and condition of the range resources in San Benito County and points out some of the more important problems connected with their use.

2373. Hormay, August L.
1940. *The effect of logging on forage.* Chron. Bot. 6(1):6-7.
Finds that grazing capacity is reduced for a year or two following logging, as tree reproduction reoccupies the ground the grazing capacity reaches a maximum and then slowly takes a downward trend.

2374. Hormay, August L.
1940. *Palatabilities of foothill range plants for cattle.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 25, 4 p. Berkeley, Calif.
Lists annual type plants and their percent palatibility in order to facilitate the completion of the Western range survey in San Benito County.

2375. Hormay, August L., and Adelbert Fausett.
1942. *Standards for judging the degree of forage utilization on California annual-type ranges.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 21, 13 p. Berkeley, Calif.
Presents a series of photographs of different range conditions and details on how to use them as standards for judging degree of utilization.

2376. Hormay, August L.
1943. *Bitterbrush in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 34, 13 p. Berkeley, Calif.
Describes *Purshia tridentata* and discusses its distribution, forage value, enemies, growth pattern, reproduction, and methods used in planting.

2377. Hormay, August L.
1943. *A method of estimating grazing use of bitterbrush.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 35, 4 p. Berkeley, Calif.
Presents a method used to measure grazing of *Purshia tridentata* which consists of estimating the amount of current twig growth grazed on marked bushes.

2378. Hormay, August L.
1943. *Observations on species composition in northeastern California meadows as influenced by moisture supply.* 6 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Reports on how changes in moisture conditions affect the composition of vegetation in meadows and makes suggestions for management beneficial to waterfowl and livestock grazing.

2379. Hormay, August L.
1944. *Moderate grazing pays on California annual-type ranges.* U.S. Dep. Agric. Leafl. No. 239, 8 p. Gov. Print. Off., Washington, D.C.
Points to the virtues of moderate grazing for sustaining high level production on annual type ranges—new plant growth will begin 2 or 3 weeks earlier than those grazed closely and will result in a relatively thick, even, vigorous cover of forage plants.

2380. Hormay, August L.
1947. *Forest grazing in California.* Soc. Am. For. Proc. Annu. Meet. Dec. 17-20, 1947:286-296.
Describes the cover types, topography, and climate of forest ranges and how they furnish a small but important portion of the forage needed by the beef cattle and sheep industries to round out their yearlong operations.

2381. Hormay, August L.
1949. *Getting better records of vegetation changes with the line interception method.* J. Range Manage. 2(2):67-69.
Points out a few ways in which the line intercept method can be used to obtain satisfactory records of density and composition and to determine yield of range vegetation.

2382. Hormay, August L., and Jay R. Bentley.
1949. *The land-variability factor in cattle-grazing experiments.* In *Proceedings of the Berkeley Symposium on Mathematical Statistics and Probability,* p. 465-467. Univ. of Calif. Press, Berkeley, Calif.
Close study of an experiment to determine the effect of forage-producing site on intensity of grazing, cattle weights, and forage changes points to the possibility of measuring range variations in pastures and using the information in interpreting the results of treatments.

2383. Hormay, August L.
1956. *How livestock grazing habits and growth requirements of range plants determine sound grazing management.* J. Range Manage. 9(6):161-164, illus.
Studies on mountain ranges in the pine timber and grassland of northeastern California show that selective grazing by livestock is a main cause of range deterioration.

2384. Hormay, August L., and Anthony B. Evanko.
1958. *Rest-rotation grazing—a management system for bunchgrass ranges.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 27, 14 p., illus. Berkeley, Calif.
Basic principles and practical steps for putting into operation a grazing system geared to improving and maintaining high forage and livestock production.

2385. Hormay, August L.
1960. *Moderate grazing pays on California annual-type ranges.* U.S. Dep. Agric. Leafl. 239 (rev.), 5 p., illus.
Defines moderate grazing, describes its beneficial effects on forage and livestock production, points out the

relationship between range utilization and range production capacity, and explains how to judge the appearance of moderately grazed range.

2386. Hormay, August L., and M. W. Talbot.
1961. *Rest rotation grazing . . . a new management system for perennial bunchgrass ranges.* U.S. Dep. Agric. Prod. Res. Rep. 51, 43 p.
Reports research which provided the basis for a grazing system designed to improve or maintain perennial bunchgrass ranges.

2387. Hormay, August L., Fred J. Alberico, and P. B. Lord.
1962. *Experiences with 2,4-D spraying on the Lassen National Forest.* J. Range Manage. 15(6):325-328, illus.
Results indicate a particular need for information on susceptibility of range plants to spraying at different growth stages.

2388. Hormay, August L.
1970. *Principles of rest-rotation grazing and multiple-use land management.* Div. Range Manage., Forest Serv. USDA Forest Serv. Training Text 4(2200), 26 p. illus.
Discusses grazing management in relation to application on 728 million acres of wildland in the Western United States.

2389. Hubbard, Richard L.
1956. *Bitterbrush seedlings destroyed by cutworms and wireworms.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 114, 2 p. Berkeley, Calif.
Cutworm and wireworm damage was found a threat to bitterbrush reseeding in northeastern California.

2390. Hubbard, Richard L.
1956. *Effect of depth of planting on the emergence of bitterbrush seedlings.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 113, 6 p., illus. Berkeley, Calif.
Two inches seems about the maximum depth from which bitterbrush seedlings can be expected to emerge with the best emergence from seed planted 0.5 to 1.5 inches deep, depending on soil-moisture conditions.

2391. Hubbard, Richard L.
1956. *The effects of plant competition upon the growth and survival of bitterbush seedlings.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 109, 9 p., illus. Berkeley, Calif.
Seedbed preparation, alone and with subsequent weeding, increased seedling growth of bitterbrush and reduced mortality.

2392. Hubbard, Richard L.
1957. *The effects of plant competition upon the growth and survival of bitterbrush seedlings.* J. Range Manage. 10(3):135-137.
See item 2391 above.

2393. Hubbard, Richard L., and B. O. Pearson.
1958. *Germination of thiourea treated bitterbrush seed in the field.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 138, 6 p. Berkeley, Calif.
Seed dormancy was successfully broken without damage to seedling emergence or survival.

2394. Hubbard, Richard L.
1958. *Hot water bath and thiourea break dormancy of wedgeleaf ceanothus seed.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 143, 4 p. Berkeley, Calif.
Hot water followed by soaking in 3 percent thiourea for 13 hours gave 31 percent germination.

2395. Hubbard, Richard L., and David Dunaway.
1958. *Variation in leader length of bitterbrush.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 145, 4 p. Berkeley, Calif.
For five bushes studied, an unrestricted random sample of 19 to 39 leaders was required for a reliable estimate of average leader length.

2396. Hubbard, Richard L., Eamor C. Nord, and L. L. Brown.
1959. *Bitterbrush reseeding—a tool for the game range manager.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 39, 14 p., illus. Berkeley, Calif.
This is a guide to successful planting of bitterbrush on western deer ranges.

2397. Hubbard, Richard L., H. Reed Sanderson, and David Dunaway.
1960. *Herbage production and carrying capacity of bitterbrush.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 157, 6 p., illus. Berkeley, Calif.
Reports weight of herbage produced by five mature bitterbrush plants and relates production to deer needs.

2398. Hubbard, Richard L., and H. Reed Sanderson.
1961. *Grass reduces bitterbrush production.* Calif. Fish and Game 47(4):391-398, illus.
Removing perennial grass and weeds beneath bitterbrush nearly doubled the number and length of bitterbrush leaders.

2399. Hubbard, Richard L., and Sturgis McKeever.
1961. *Meadow mouse girdling—another cause of death*

of reseeded bitterbrush plants. Ecology 42(1):198, illus.
On a reseeded bitterbrush area, mice killed 5 percent of the plants and damaged 15 percent.

2400. Hubbard, Richard L., and H. Reed Sanderson.
1961. *When to plant bitterbrush—spring or fall?* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 64, 21 p., illus. Berkeley, Calif.
For success in planting bitterbrush, the soil at planting depth must remain moist during germination and emergence.

2401. Hubbard, Richard L., Pinhaus Zusman, and H. Reed Sanderson.
1962. *Bitterbrush stocking and minimum spacing with crested wheatgrass.* Calif. Fish and Game 48(3):203-208, illus.
Individual bitterbrush plants on a 1953 seeding began dying in 1959, apparently from lack of moisture with plants within 2 feet of crested wheatgrass seriously damaged.

2402. Hubbard, Richard L.
1964. *A guide to bitterbrush seeding in California.* 30 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A 5-step prescription for seeding is explained and uses of the plant in rehabilitation of big-game ranges is given.

2403. Hubbard, Richard L.
1974. *Castanopsis* (D. Don) Spach. Chinkapin. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 276-277, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

2404. Hubbard, Richard L.
1974. *Rhamnus* L. Buckthorn. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 704-708, illus.
See item 2403 above.

2405. Hutchinson, C. B., and E. I. Kotok.
1942. *The San Joaquin Experimental Range.* Calif. Agric. Exp. Stn. Bull. 663, 145 p. Berkeley, Calif.
Contains a collection of papers by various authors describing the Experimental Range, wildlife relations, ranch organization and management, forage crop and herd management.

2406. Hyder, D. N., C. Eugene Conrad, and others.
1963. *Frequency sampling in sagebrush-bunchgrass vegetation.* Ecology 44(4):740-746, illus.
Reports on efficient quadrat sizes and allocations of sampling units for frequency sampling, and reviews pertinent theoretical considerations.

2407. Hylton, Lynn O., and Albert Ulrich.
1968. *Critical nitrate-N concentrations for growth of two strains of Idaho fescue.* J. Range Manage. 21(5):321-325, illus.
Nitrate-N in shoots should be above 500 ppm, dry basis, during active vegetative growth if maximum forage production is desirable.

2408. Hylton, Lynn O., Donald R. Cornelius, and Albert Ulrich.
1968. *Sulfur needs of Spanish clover and the relation of sulfur and other nutrients as diagnosed by plant analysis.* J. Range Manage. 21(3):129-135.
Top growth was affected more than root growth by changes in sulfur supply and protein synthesis in the shoots was little affected by sulfur deficiency.

2409. Hylton, Lynn O., and Albert Ulrich.
1969. *Comparative growth stages and plant parts for critical nitrate-N concentration of squirreltail.* J. Range Manage. 22(3):188-192, illus.
The critical nitrate-N concentration was not appreciably affected by plant maturity when recently-matured blades rather than entire shoots were analyzed for nitrate-N.

2410. Hylton, Lynn O., Donald R. Cornelius, and Albert Ulrich.
1970. *Nitrogen nutrition and growth relations of tall and intermediate wheatgrasses.* Agron. J. 62:353-356.
In a common and favorable environment, intermediate wheatgrass grew faster than tall wheatgrass.

2411. Hylton, Lynn O.
1974. *Penstemon* Mitch. Penstemon. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 574-575, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

2412. Liacos, Leonidas G., and Eamor C. Nord.
1961. *Curlleaf cercocarpus seed dormancy yields to acid and thiourea.* J. Range Manage. 14(6):317-320, illus.
Curlleaf cercocarpus seed treated for 5 minutes in concentrated sulfuric acid and 4 hours in 3 percent thiourea yielded 76 percent germination compared to 14 percent germination for untreated seed.

2413. McConnen, Richard J., C. B. McCorkel, and D. D. Caton.

1963. *Feed-livestock relationships, a model for analyzing management decisions.* Agric. Econ. Res. 15(2):41-48.
Livestock production is considered as a three-stage production process, (a) a feed procurement, (b) feed consumption, and (c) feed conversion, and a general economic model is developed.

2414. McConnen, Richard J.
1965. *Relation between the pattern of use and the future output from a flow resource.* J. Farm Econ. 47(2):311-323.
Examines the results from a grazing intensity study conducted in the Northern Great Plains to determine the impact of human action on the future rates of flow from flow resources.

2415. McKell, Cyrus M., Charles A. Graham, and Alma M. Wilson.
1960. *Benefits of fertilizing annual range in a dry year.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 172, 9 p., illus. Berkeley, Calif.
Range fertilization resulted in earlier range readiness, increased herbage production, and increased protein content of herbage, during droughty 1959, but at somewhat reduced level compared to more favorable years.

2416. Neal, Donald L., and Lee R. Neal.
1965. *A new electronic meter for measuring herbage yield.* U.S. Forest Serv. Res. Note PSW-56, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A new instrument, called the Hetrodyne Vegetation Meter, which measures herbage yield and utilization, was built and tested.

2417. Neal, Donald L., Richard L. Hubbard, and C. Eugene Conrad.
1969. *A magnetic point frame.* J. Range Manage. 22(3):202-203, illus.
The point frame has been improved by using pot magnets as brakes for pins.

2418. Neal, Donald L., and Jerry L. Neal.
1973. *Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part I. History and development.* J. Br. Grassl. Soc. 28(2):81-89, illus.
Describes briefly the significant steps in the development of electronic capacitance instruments for estimating weight of vegetation.

2419. Neal, Donald L.
1974. *Carpenteria californica* Torr. Carpenteria. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 265, illus.
Summarizes data on growth habit, occurrence, uses, flowering, fruiting, seed collection, extraction, germination, and nursery practices.

2420. Neal, Donald L.
1974. *Dendromecon rigida* Benth. Stiff Bushpoppy. In *Seeds of woody plants in the United States.* U.S. Dep. Agric., Agric. Handb. 450, p. 372, illus.
See item 2419 above.

2421. Neal, Donald L., and H. Reed Sanderson.
1975. *Thiourea solution temperature and bitterbrush germination and seedling growth.* J. Range Manage. 28(5):421-423, illus.
Normal germination and seedling growth resulted at temperatures between 60° F. and 140° F.; below 60° F. there was a slight reduction in germination, but seedling growth was normal.

2422. Nord, Eamor C., and G. E. Whitacre.
1957. *Germination of fourwing saltbush seed improved by scarification and grading.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 125, 5 p. Berkeley, Calif.
Germination success is inversely related to seed size with moderate scarification hastening the rate of germination and heavy scarification increasing total germination.

2423. Nord, Eamor C.
1958. *Rice hulls improve drilling bitterbrush seed.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 134, 5 p. Berkeley, Calif.
Gives operating hints and seeding chart for sowing with rice hulls for uniform distribution with standard fluted-feed grain drill.

2424. Nord, Eamor C.
1959. *Bitterbrush plants can be propagated from stem cuttings.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 149, 4 p., illus. Berkeley, Calif.
Describes method of making *Purshia tridentata* stem cuttings and reports rooting success in one trial.

2425. Nord, Eamor C.
1963. *Bitterbrush seed harvesting: when, where, and how.* J. Range Manage. 16:258-261, illus.
A seed ripening prediction chart is given to enable collectors to schedule bitterbrush seed harvesting throughout California, and several sites possessing good seed production potential are identified.

2426. Nord, Eamor C., Edward R. Schneegas, and Hatch Graham.

1967. *Bitterbrush seed collecting—by machine or by hand.* J. Range Manage. 20(2):96-99, illus.
Collecting seed by hand using Forest Service crews was the most economical method; collecting with the experimental browse seed harvester was the most expensive; and purchase from private collectors was intermediate in cost.

2427. Nord, Eamor C., and Joe R. Goodin.
1970. *Rooting cuttings of shrub species for plantings in California wildlands.* USDA Forest Serv. Res. Note PSW-213, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Fourwing, Gardner's Nuttall's, and allscale saltbushes and creeping sage rooted successfully under intermittent mist from green tip and ripewood stem cuttings taken in spring and fall.

2428. Nord, Eamor C., Patrick F. Hartless, and W. Dennis Nettleton.
1971. *Effects of several factors on saltbush establishment in California.* J. Range Manage. 24(3):216-223, illus.
Emergence and survival were significantly higher in seedlings grown at the ½-inch depth than in the 1-inch depth.

2429. Nord, Eamor C., Louis E. Gunter, and Stuart A. Graham, Jr.
1971. *Gibberellic acid breaks dormancy and hastens germination of creeping sage.* USDA Forest Serv. Res. Note PSW-259, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The most effective, practical, and lasting treatment tested was by a gibberellic acid soak under constant agitation at 500 ppm for 4 hours.

2430. Nord, Eamor C.
1956. *Quick testing bitterbrush seed viability.* J. Range Manage. 9(4):193-194, illus.
Describes a four-step procedure for determining viability of bitterbrush seed.

2431. O'Regan, William G., and C. Eugene Conrad.
1975. *Number of pins in two-stage stratified sampling for estimating herbage yield.* USDA Forest Serv. Res. Note PSW-300, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a procedure to compute the effect of the number of pins in a pin frame on the variance of estimated herbage yield.

2432. Pearson, B. O.
1957. *Bitterbrush seed dormancy broken with thiourea.* J. Range Manage. 10(1):41-42.
Highly dormant bitterbrush seed germinated 85 percent after soaking for 3 to 5 minutes in a 3 percent solution of thiourea.

2433. Rader, Lynn.
1961. *Economic evaluation of range improvement and management practices.* Am. Soc. Range Manage. 14th Annu. Meet., Jan. 31-Feb. 3, 1961:60-61.
Despite technical progress in range management, little has been done to determine the economic feasibility of recommended practices.

2434. Rader, Lynn.
1961. *Grazing management pays on perennial grass range during drought.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 179, 2 p. Berkeley, Calif.
Two consecutive drought years reduced livestock gains and length of grazing season on many grazing units, but under rest-rotation management cattle were carried for the full grazing season with normal weight gains.

2435. Rader, Lynn, and Raymond D. Ratliff.
1962. *A new idea in point frames.* J. Range Manage. 15(3):182-183, illus.
New version of the point frame employs notches rather than holes to guide the pins and requires one pin rather than a set of ten.

2436. Ratliff, Raymond D., and Lynn Rader.
1962. *Drought hurts less with rest-rotation management.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 196, 4 p., illus. Berkeley, Calif.
Despite a third successive year of drought, forage production on a practical scale trial of rest-rotation grazing management was adequate for normal grazing use.

2437. Ratliff, Raymond D.
1962. *Preferential grazing continues under rest-rotation management.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 206, 6 p., illus. Berkeley, Calif.
Even with much attention to livestock distribution, preferential grazing still occurs under rest-rotation management; however, this management provides needed rest for preferred areas and forces cattle to use some areas they otherwise might not graze.

2438. Ratliff, Raymond D., and Jack N. Reppert.
1965. *Locating pairs of comparable study areas . . . new system developed.* U.S. Forest Serv. Res. Note PSW-129, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes a system for locating pairs of "comparable" areas on which to establish study plots.

2439. Ratliff, Raymond D., and Stanley E. Westfall.
1971. *Non-grazing and gophers lower bulk density and acidity in annual-plant soil.* USDA Forest Serv. Res. Note PSW-254, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A range with this soil, after 34 years of non-grazing use, had a lower surface bulk density and lower acidity than an adjacent grazed range.

2440. Ratliff, Raymond D.
1972. *Livestock grazing not detrimental to meadow wildflowers.* USDA Forest Serv. Res. Note PSW-270, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Rest-rotation grazing produced desirable results compared to free-choice grazing, but it did result in a reduction in flower-producing forbs.

2441. Ratliff, Raymond D., Stanley E. Westfall, and Richard J. McConnen.
1972. *More California-poppy in stubble field than in old field.* USDA Forest Serv. Res. Note PSW-271, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A site disturbance which produced a harsh microclimate or reduced competition or both will probably favor California-poppy.

2442. Ratliff, Raymond D., Jack N. Reppert, and Richard J. McConnen.
1972. *Rest-rotation grazing at Harvey Valley—range health, cattle gains, costs.* USDA Forest Serv. Res. Paper PSW-77, 24 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Compares short-term costs to returns and evaluates the ecological benefits and cattle weight gains from rest-rotation grazing in northeastern California.

2443. Ratliff, Raymond D.
1973. *Shorthair meadows in the high Sierra Nevada . . . an hypothesis of their development.* USDA Forest Serv. Res. Note PSW-281, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Proposes an hypothesis that can help to understand the shorthair meadows and in deciding on management needed to restore damaged sites.

2444. Ratliff, Raymond D., and Jack N. Reppert.
1974. *Vigor of Idaho fescue grazed under rest-rotation and continuous grazing.* J. Range Manage. 27(6):447-449.
Vigor was maintained at a higher level over the 5-year period with rest-rotation grazing, as indicated by vegetative shoot lengths and flower stalk numbers.

2445. Ratliff, Raymond D., and Richard L. Hubbard.
1975. *Clipping affects flowering of California-poppy at two growth stages.* USDA Forest Serv. Res. Note PSW-303, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Through the early reproductive stage, a single clipping had little effect, but clipping at either the start or the peak of vernal flowering reduced the display of spring flowers.

2446. Reed, Merton J., and Ronald A. Peterson.
1961. *Vegetation, soil, and cattle responses to grazing on northern plains range.* U.S. Dep. Agric. Tech. Bull. 1252, 79 p., illus.
Reports a 14-year study of responses to different intensities of experimental grazing, and includes recommendations for stocking summer and winter ranges, for judging correct herbage removal, and for checking range condition.

2447. Reed, Merton J., and Jon M. Skovlin.
1963. *Estimating grazing values for layout and calibration of experimental ranges.* U.S. Dep. Agric. Misc. Publ. 940, 142-148, illus.
The more common methods for estimating grazing values are discussed in the light of current knowledge, recommendations are made, and research needs are pointed out.

2448. Reppert, Jack N., and Lisle R. Green.
1958. *Annotated bibliography of publications from the San Joaquin Experimental Range.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 27, 32 p. Berkeley, Calif.
Provides brief content descriptions of 135 publications dealing with range management, livestock production, zoological, and other aspects of the cooperative research program since establishment in 1934.

2449. Reppert, Jack N.
1960. *Forage preference and grazing habits of cattle at the Eastern Colorado Range Station.* J. Range Manage. 13:58-65.
Enumerates native forage species and parts of these species which were selected and consumed by cattle grazing sandhill ranges.

2450. Reppert, Jack N., and E. J. Woolfolk.
1960. *Research at the San Joaquin Experimental Range.* 11 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A brief description of the San Joaquin Experimental Range, and its past and present research programs.

National Forest campgrounds. In *Recreation in wildland management—selected speeches and discussions.* 14th Annual Univ. Calif. Ext. For. Field School, April 9-13, 1962. 4 p.
Recreation impact on campsite quality is impaired by poor seedling survival and reproduction, decreases in shrubby ground cover, soil compaction, and decreased amounts of forest litter.

2554. Nord, Eamor C., and Arthur W. Magill.
1963. *A device for gaging campground screening cover.* J. For. 61:450-451, illus.
Describes the construction and method of using a simple device for measuring the screening value of vegetation and other obstructions to vision in forest recreation studies.

2555. Paine, Lee A.
1966. *Accidents caused by hazardous trees on California forest recreation sites.* U.S. Forest Serv. Res. Note PSW-133, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
From 1959 through 1966, tree failures caused an average of more than two injuries or deaths per year on forest recreation sites in California.

2556. Paine, Lee A.
1967. *Effective tree hazard control on forested recreation sites . . . losses and protection costs evaluated.* U.S. Forest Serv. Res. Note PSW-157, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Records of falling trees and limbs and resulting accidents, suggest that control of this hazard should emphasize reduction of losses from bole failure among conifers and from limb failures among oaks.

2557. Paine, Lee A.
1967. *Tree hazard control on recreation sites . . . estimating local budgets.* U.S. Forest Serv. Res. Note PSW-160, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Assignment of priorities to the various classes of tree defects affords a logical approach to efficient budgeting and effective use of control funds.

2558. Paine, Lee A.
1971. *Accident hazard evaluation and control decisions on forested recreation sites.* USDA Forest Serv. Res. Paper PSW-68, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The individual factors responsible for hazard are defined and discussed, and a practical approach to hazard rating is explained.

2559. Paine, Lee A.
1973. *Administrative goals and safety standards for hazard control on forested recreation sites.* USDA Forest Serv. Res. Paper PSW-88, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
With a safety standard based on a defined goal and with a uniform hazard-rating procedure, recreation-site managers can provide a consistent level of safety throughout an administrative region.

2560. Streeby, Larry L., and Robert H. Twiss.
1966. *Research and forest recreation.* Am. For. 53:12-13, 61.
Studies on forest management for recreation is described with references to recent work.

2561. Twiss, Robert H., and Harry W. Camp.
1963. *Forest recreation research at the Pacific Southwest Forest and Range Experiment Station.* U.S. Forest Serv. Res. Note PSW-12, 7 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Research problems, approaches, studies, and plans are summarized.

2562. Twiss, Robert H.
1963. *Information and outdoor recreation research.* U.S. Forest Serv. Res. Note PSW-3, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The scientific information needs of outdoor recreation research are considered in light of some existing and future methods of information acquisition, storage, and retrieval.

2563. Twiss, Robert H.
1963. *An interdisciplinary approach to outdoor recreation research.* J. For. 61:580-582.
Investigates the need to build conceptual frameworks for relating recreation problems to established disciplines and for facilitating interdisciplinary research and considers systems analysis and development as one scheme for organizing research effort.

2564. Twiss, Robert H.
1965. *Regional landscape design—an approach to research and education.* Proc. Natl. Conf. Intr. Landscape Architect., Harvard Univ. 1:17-24.
Suggests a working definition of regional landscape design and considers the contributions of landscape architecture, forestry, and other professions in solving regional problems.

2565. Twiss, Robert H.
1965. *Research on the environment of travel.* Proc. 8th

Annu. Meet. West. Counc. Travel Res. 6 p.
Research on travel and outdoor recreation needs to consider more fully the interrelation between the traveler and his social and natural environment.

2566. Twiss, Robert H., and R. Burton Litton.
1966. *Resource use in the regional landscape.* Nat. Resour. J. 6(1):76-81.
Analyzes the concept of 'scenery,' which is increasingly being invoked in the design of scenic highways, scenic corridors, and forest management areas, and in metropolitan open space.

2567. Twiss, Robert H.
1966. *Science and the regional landscape.* Proc. 16th Alaskan Sci. Conf. 1965:284-295.
Suggests that it should be possible to study and manage the regional landscape in terms of nature, beauty, meaning, and imageability.

2568. Twiss, Robert H.
1967. *Recreationists as decision makers.* West. For. and Conserv. Assoc. Proc. 1966:42-46.
Public relations programs are useful, but land-use actions that fully incorporate recreationist values will be more telling.

2569. Twiss, Robert H., and R. Burton Litton.
1967. *Research on forest environmental design.* Soc. Am. For. Proc. 1966:209-210.
Research is needed to further describe factors of visual perception and people's response to the forest landscape in terms of present levels of understanding, and attitudes toward management practices.

2570. Twiss, Robert H.
1969. *Conflicts in forest landscape management—the need for forest environmental design.* J. For. 67(1):19-22.
Suggests that design, architecture, and planning professions must be brought into play in developing forest environments.

2571. Twiss, Robert H., David Streatfield, Eugene Kojan, and Arthur W. Magill.
1969. *Nicasio—hidden valley in transition.* 50 p., illus. Marin County Planning Dep., San Rafael, Calif.
Provides an analysis of the environment and of the natural and historical bases of landscape quality of Nicasio, in Marin County, California.

2572. Twiss, Robert H., and Louise Parker.
1971. *Growing with nature.* In *Yearbook of Agriculture. A good life for more people.* p. 33-38, illus. U.S. Dep. Agric., Washington, D.C.
A cooperative landscape inventory and analysis will be used as the basis of a master plan for Nicasio, a small town north of San Francisco.

2573. Wagener, Willis W.
1963. *Judging hazard from native trees in California recreational areas: a guide for professional foresters.* U.S. Forest Serv. Res. Paper PSW-1, 29 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Offers suggestions for conducting tree hazard inspections, and proposes standards for judging the potential hazard of defects.

FOREST ECONOMICS AND FOREST PRODUCTS

Forest Economics

2574. Brundage, M. R., M. E. Kreuger, and Duncan Dunning.
1933. *The economic significance of tree size in western Sierra Nevada lumbering.* Calif. Agric. Exp. Stn. Bull. No. 549, 61 p.
A coordinated logging and milling study was conducted in order to determine costs and values for each species, size and grade of logs and trees.

2575. Brundage, M. R.
1934. *Tree size: an index to operating costs and values. coastal region.* Am. Pulpwood Assoc. Tech. Paper.
Presents information relating tree size to cost and value, and suggests that smaller trees do not yield maximum profits.

2576. Brundage, M. R.
1938. *Valuation of trees and cutting systems on four sample plots, Blacks Mountain Experimental Forest, 1938.* 4 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Outlines new log grading rules used for calculating lumber selling values of ponderosa pine logs and to compare three cutting systems.

2577. Camp, H. W.
1967. *Timber supply picture in California's north coastal region.* Am. Pulpwood Assoc. Tech. Paper, July 1967:3-4.
Possible loss of old-growth to parks will have an effect on conversion period, as will progress in development of markets for young-growth.

2578. Crafts, E. C., and Rene Bollaert.
1942. *Some social and economic effects of timber*

utilization and management in Modoc County, California. 41 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Recommends the use of sustained yield rather then "liquidation" logging for improving local economies in timber-growing areas.

2579. Josephson, H. R.
1937. *Economic research and Forest planning.* J. For. 35(8):744-746.
Discusses the desirability of sustained-yield forest management and the need to consider economic trends in planning, including taxation and tariff policies, in order to realize the highest monetary and social returns from the use of forest resources.

2580. Josephson, H. R.
1939. *Best use of forest land.* West. Farm Econ. Assoc. Proc. 1939:39-47.
Discusses competitive and supplementary relationships between forestry and agriculture, the intensity of forest land use, and policies to promote best use in order to realize productive forests, profitable and stable industries, and permanent forest employment.

2581. Josephson, H. R.
1941. *Factors affecting income from second-growth forests in the western Sierra Nevada.* Calif. Agric. Exp. Stn. Bull. 658, 72 p. Berkeley, Calif.
Discusses costs, yield and incomes involved in timber management and utilization to aid in developing policies and practices that will make possible forest management for continuous production.

2582. Kotok, E. I., Evan W. Kelley, C. F. Evans, and Burt P. Kirkland.
1933. *Ownership responsibilities, costs, and returns.* In *A national plan for American forestry,* p. 1303-1328. U.S. Forest Serv., Washington, D.C.
Examines the costs of managing and protecting national, state and private forests, and concludes that the forests, maintained at a level of productivity sufficient to meet national requirements, should produce a gross return of about $700,000,000.

2583. Kotok, E. I.
1936. *Financial handicaps.* The West. Range 1936:193-211.
Explains the way in which financial factors beyond the control of the producers have influenced business management and range practice, tending toward range depletion.

2584. Kotok, E. I.
1938. *Regulating the uses of private land—an essential function of modern government.* First Pacific Southwest Planning Conf. Proc. Santa Barbara, 1938:36-41.
Considers basic resources, exploitive processes, and the application of regulatory measures which may be required to protect the interests of society including mandatory Federal, state, or cooperative control.

2585. Kotok, E. I.
1939. *Some economic problems in Pacific Coast forestry.* Pacific Coast Econ. Assoc. Proc., 17th Annu. Conf. 1939:90-94.
Discusses the exploitation of the forests resulting from a laissez-faire policy and stresses the need for better management of private lands by public regulation and/or acquisition.

2586. McConnen, Richard J., Daniel I. Navon, and Elliot L. Amidon.
1966. *Efficient development and use of forest lands: An outline of a prototype computer-oriented system for operational planning.* For. Comm. (London), Forest Rec. No. 59:18-32, illus.
The prototype system consists of a computer-oriented system called MIADS; an analytical model in linear programming format; solutions for this model; and auxiliary computer programs to update resource inventory information.

2587. McConnen, Richard J.
1967. *The use and development of America's forest resources.* Econ. Bot. 21(1):2-14, illus.
The increased importance of recreation, water, and other multiple uses will have a great influence on the future development and use of forest lands.

2588. McConnen, Richard J., Elliot L. Amidon, and Daniel I. Navon.
1967. *The use of operation research techniques in determining allowable cut.* Soc. Am. For. Proc. 1966:109-115, illus.
Operations research models can be used to determine the optimum way of manipulating a forest ecosystem to achieve certain goals.

2589. McConnen, Richard J., and Elliot L. Amidon.
1970. *A computer-based approach to evaluating plantation alternatives—a case study of Pinus contorta in Ireland.* Forestry 43(1):31-43, illus.
Economic model selection and computer methodology were used to calculate discounted net revenues for 432 combinations of sites, costs, and returns with fixed thinning schedules.

2590. Newport, C. A.
1958. *Can the quality index concept be used in*

ponderosa pine and sugar pine? U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 141, 6 p. Berkeley, Calif.
Concludes that the quality index concept cannot be used in appraisals of these species because such an index assumes satisfactory stability in lumber price ratios.

2591. Poli, Adon, and E. V. Roberts.
1958. *Economics of the utilization of commercial timberland on livestock ranches in northwestern California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 25, 51 p., illus. Berkeley, Calif.
On suitable terrain and exposures, and with proper management, certain timber soils can be profitably converted to grassland, but good quality timberland will yield more in the long run if left in timber than if converted to grassland.

2592. Teeguarden, Dennis E.
1968. *Economics of replacing young-growth ponderosa pine stands . . . a case study.* U.S. Forest Serv. Res. Paper PSW-47, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Compares expected capital value growth of five 70- to 80-year-old ponderosa pine stands on the Challenge Experimental Forest, near Challenge, California, with cost of delaying harvest, defined as the sum of stock-holding and land-holding costs.

2593. Teeguarden, Dennis E., and K. R. Werner.
1968. *Integrating forest-oriented recreation with timber growing—a case study of economic factors.* Calif. Agric. 22(10):10-12, illus.
Reports a study of the economics of integrating timber growing with the sale of two kinds of forest-oriented recreation services, vacation homesites and campground facilities

2594. Vaux, H. J.
1948. *Some economic aspects of growing sugar pine in California.* U.S. Forest Serv. Calif. Forest and Range Res. Note 58, 33 p. Berkeley, Calif.
Examines past sugar pine consumption, markets, trends in value, the impact of blister rust control costs, and the outlook for the future

Forest Products Utilization

2595. Baker, H. L.
1959. *California's timber industries.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 38, 19 p., illus. Berkeley, Calif.
Gives an analytical description of California's timber industries, primarily lumber, plywood, and pulp and discusses some historical background.

2596. Bean, L. M.
1933. *Production of lumber, lath, and shingles in California, 1932.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 3, 2 p. Berkeley, Calif.
Gives a preliminary statement based on returns from the lumber census conducted by the Forest Service for the Bureau of the Census.

2597. Bean, L. M.
1934. *Production of lumber, lath, and shingles in California, 1933.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 6, 2 p. Berkeley, Calif.
See item 2596 above.

2598. Bean, L. M.
1935. *Production of lumber, lath, and shingles in California and Nevada, 1934.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 7, 1 p. Berkeley, Calif.
See item 2596 above.

2599. Bean, L. M.
1936. *Production of lumber and other timber products in California and Nevada, 1935.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 3, 2 p. Berkeley, Calif. Also, Timberman 37(10):82.
See item 2596 above.

2600. Bean, L. M.
1937. *Preliminary statement on production of lumber, lath, and shingles in California, 1936.* 2 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif. Also, West Coast Lumberman 64(7):72.
See item 2596 above.

2601. Bean, L. M.
1938. *Preliminary statement on production of lumber and other timber products in California, 1937.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 10, 2 p. Berkeley, Calif. Also, West Coast Lumberman 65(12):50.
See item 2596 above.

2602. Bollaert, Rene.
1941. *A preliminary survey of utilization conditions for second-growth timber products from the western Sierra Nevada.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 14, 13 p. Berkeley, Calif.
Shows the downward trend in the use of second-growth

lumber and recommends that forest owners market old-growth timber rather than second-growth lumber.

2603. Boone, R. Sidney.
1965. *The market for lumber and other wood products in Hawaii's transportation industry.* U.S. Forest Serv. Res. Note PSW-86, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Hawaii's transportation industry uses about 8 million board feet of lumber each year; there is also a small but continuing market for produce and vegetable containers.

2604. Boone, R. Sidney.
1965. *Service life of telephone poles on the island of Hawaii.* U.S. Forest Serv. Res. Note PSW-96, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
After 20 years, untreated redwood poles averaged 94 percent still serviceable, pressure treated Douglas-fir 84 percent serviceable, pressure treated southern pine 74 percent serviceable, and 75 percent of the untreated western red cedar remained serviceable.

2605. Boone, R. Sidney.
1966. *Paintability of two Hawaii-grown woods—first progress report.* U.S. Forest Serv. Res. Note PSW-116, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Finds that after exposure for 1 year robusta eucalyptus and Australian toon appear as good as redwood and Douglas-fir in their paintholding ability on simulated vertical house siding.

2606. Boone, R. Sidney.
1967. *Moisture content of wood for interior use . . . Douglas-fir and robusta eucalyptus samples studied.* U.S. Forest Serv. Res. Note PSW-152, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Test panels showed little seasonal variation in equilibrium moisture content of wood at 19 locations on Oahu, Hawaii.

2607. Brundage, M. R.
1930. *When is a tree—?* Calif. Countryman 16(7):8-9, 32.
The consumer should be aware that the future of timber supplies and costs depends on sound silvicultural and economic administration by the Forest Service.

2608. Brundage, M. R.
1936. *Comparative lumber selling values of different grades and sizes of redwood logs.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 8, 8 p. Berkeley, Calif.
Notes on a preliminary analysis of mill-production study in Humboldt County conducted in 1935.

2609. Brundage, M. R., and T. J. Orr, Jr.
1936. *Comparative yield of lumber grades from three grades of redwood logs classified on the basis of their superficial appearance in the standing trees.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 12, 4 p. Berkeley, Calif.
Utilizes a simplified three-grade classification and presents a graph showing the relation of average fob-mill green lumber selling value to log diameter.

2610. Brundage, M. R., and T. J. Orr, Jr.
1936. *Lumber selling values of logs from insect-infested ponderosa and Jeffrey pine trees salvaged in 1935 on an east-side pine region area.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 9, 8 p. Berkeley, Calif.
Presents tables comparing realization values from logs of the same external grade appearance, insect-stain class, and log-diameter group; Jeffrey pine logs were consistently lower in value than the ponderosa pine logs.

2611. Brundage, M. R., and T. J. Orr, Jr.
1936. *Through mill, kiln, and planer with 100 trees.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 11, 7 p. Berkeley, Calif.
Presents some preliminary summaries from a study in which boards from various classes of ponderosa pine logs were individually numbered and graded, reinspected again rough-dry, and finally reinspected after surfacing.

2612. Brundage, M. R.
1939. *Summary of the office report on a proposed new log grade classification for California pine region virgin timber.* 13 p. U.S. Forest Serv. Calif. Forest and Range Exp. Stn., Berkeley, Calif.
Presents details of the "knot-counting" system of log grading and proposes standards for its use.

2613. Burgan, Robert E., and Wesley H. C. Wong, Jr.
1971. *Forest-products harvested in Hawaii—1969.* USDA Forest Serv. Res. Note PSW-239, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Primary forest products harvested in Hawaii in 1969 had a value of $331,000 with sawlogs and veneer logs the most important primary forest products.

2614. Burgan, Robert E., Wesley H. C. Wong, Jr., Roger G. Skolmen, and Herbert L. Wick.
1971. *Guide to log defect indicators in koa, ohia . . . preliminary rules for volume deductions.* 6 p., illus.

Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

An exploratory study provides the first volume deduction rules for various surface defect indicators common on koa (Acacia koa) and ohia *(Metrosideros collina)* trees in Hawaii.

2615. Burks, George F., and Russell W. Beeson.

1945. *Lumber requirements of the California fruit and vegetable industries.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 46, 12 p. Berkeley, Calif.

Summarizes the lumber requirements in terms of both shook and gross footage and predicts that fruit and vegetable producers will be forced to rely more on lumber sources outside the state.

2616. Burks, George F., R. H. May, Alexander Simontacchi, Blanche M. Fadie, and Grace H. Stovall.

1946. *Production of lumber, lath, and shingles in California and Nevada, 1945.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 50, 7 p. Berkeley, Calif.

Preliminary statement based on returns from the lumber census conducted by the Forest Service for the Bureau of the Census.

2617. Burks, George F., H. J. Vaux, R. H. May, and A. Simontacchi.

1948. *Commodity production from commercial forest land in California—1946.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 6, 38 p. Berkeley, Calif.

Presents data on the production of primary forest products, describes the origin, character and species of material removed from timber growing stock and the proportionate use of this material by various forest product industries.

2618. Burks, George F., and R. W. Beeson.

1948. *Irrigation agriculture in its relation to lumber requirements as illustrated by the California fruit and vegetable industry.* Unasylva 2(5):237-242.

Estimates that the fruit and vegetable industries in California used approximately 721 million board feet of shook annually during the 5 years 1940-44.

2619. Burks, George F.

1949. *Estimated lumber production in California—1948.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 65, 6 p. Berkeley, Calif.

Presents tables of lumber production by species and production size class.

2620. Claxton, H. Dean.

1966. *Computer simulation of kiln drying.* Proc. 18th. Annu. Meet. West. Dry Kiln Clubs:55-61.

A simulation—which will be used for predicting the results of specific drying schedules—was designed to predict the distribution of moisture along the length of an incense-cedar pencil slat from end to center after a specified drying period.

2621. Claxton, H. Dean.

1972. *Optimum target sizes for a sequential sawing process.* USDA Forest Serv. Res. Paper PSW-87, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Reports development and application of a multistage decision technique for obtaining optimum settings for saws in a sequential sawing process.

2622. Crafts, E. C.

1941. *Some economic facts about the California lumber and timber products industry and size of its dependent population.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 17, 18 p. Berkeley, Calif.

Discusses the adverse impact of increased activity in defense-related industries on the California lumber and timber products industries.

2623. Crafts, E. C., F. G. Leonard, M. A. Bateman, W. E. Hallin, and H. Garland.

1942. *Preliminary estimate of production of lumber, lath, and shingles in California, 1941.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 19, 4 p. Berkeley, Calif.

Preliminary statement based on returns from the lumber census conducted by the Forest Service for the Bureau of the Census.

2624. Crafts, E. C.

1942. *Some effects of defense on wood utilization in California.* J. For. 40(4):285-290.

Numerous defense contracts awarded before World War II had a profound effect on industrial activity, raising production and employment to new highs; however there were some difficulties in transportation, and in maintaining an adequate supply of plywood and other building materials.

2625. Curry, J. R.

1932. *The Morse sawmill at Cooptown believed to be the oldest and longest-lived mill in the United States.* Am. Forests 38(6):354-356, 382.

Indicates that the oldest sawmill in the United States is the Morse mill, built in 1840, and still operating under the same control in 1932.

2626. Drow, John T., and L. N. Eriksen.

1947. *California red fir compares favorably with other*

western species. Calif. Lumber Merchant 26(11):45, 46.

Tests show that *Abies magnifica* compares favorably with other western species in weight per cubic foot, volumetric shrinkage, bending strength, compressive strength, stiffness, hardness, and shock resistance.

2627. Duncan, Don A., and Harold W. Wolfram.
1970. *Fenceposts butt-soaked in pentachlorophenol still sound after 22 years.* USDA Forest Serv. Res. Note PSW-221, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

After nearly 23 years' service, every untreated post, except incense-cedar heartwood and manzanita, had rotted, but most treated posts were sound.

2628. Duncan, Don A.
1971. *Save a nickel, save a dime.* West. Livestock J. (Pacific Slope Ed.) 49(64):42, illus.

A simple penta treatment for wood posts is a wise investment over the long haul.

2629. Echols, Robert M.
1972. *Product suitability of wood . . . determined by density gradients across growth rings.* USDA Forest Serv. Res. Note PSW-273, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Accumulated means of wood density classes can be used to synthesize single growth-ring density curves to determine suitability of wood for various uses.

2630. Echols, Robert M., and R. A. Currier.
1973. *Comparative properties of Douglas-fir boards made from parallel-laminated veneers vs. solid wood.* For. Prod. J. 23(2):45-47, illus.

In static bending tests the strength of 1- by 6-inch fabricated boards compared favorably with clear, vertical-grain, solid wood boards for modulus of elasticity, modulus of rupture, and maximum load at failure.

2631. Ericksen, Leyden N.
1957. *Raw materials available for the particle board industry.* No. Calif. Sec. Forest Prod. Res. Soc. Proc. 1957. 6 p.

Reviews types of raw material suitable for particle board manufacture and summarizes volumes and types of manufacturing wood residues available in northern California.

2632. Ericksen, Leyden N.
1960. *California boosts wood industry.* West. Conserv. J. 17(5):39-41, illus.

Reviews the impressive changes in California's forest industries during recent years: increased lumber production, particularly of Douglas-fir; growth of plywood industry; use of plant residue for pulp; particle board production; bark utilization; and more intensive utilization at mills.

2633. Frazier, George D., John H. Weber, and Kenneth D. MacKenzie.
1964. *The Los Angeles furniture industry. Organization of the industry.* West. Furniture Manuf. 19(9): 13-17.

The California furniture industry, second in the nation in number of manufacturing establishments and third in value-added-by-manufacturing, is a vastly complicated industrial organization of many, small, highly specialized plants.

2634. Frazier, George D., John H. Weber, and Kenneth D. MacKenzie.
1964. *The Los Angeles furniture industry. 2-Lumber and plywood consumption.* West. Furniture Manuf. 19(10):24-26, illus.

Manufacturers of case goods, upholstered furniture, and furniture parts consume 100 million board feet of lumber per year, 58 percent hardwoods, 42 percent softwoods.

2635. Frazier, George D.
1965. *Estimated demand for lumber and plywood in Hawaii by the year 2000.* U.S. Forest Serv. Res. Paper PSW-23, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Total lumber consumption by the year 2000 is expected to be between 78 and 128 million board feet with plywood consumption estimated at 40 million square feet.

2636. Fullaway, S. V., Herman M. Johnson, and C. L. Hill.
1928. *The air seasoning of western softwood lumber.* U.S. Dep. Agric. Dep. Bull. 1425, 60 p. U.S. Gov. Print. Off., Washington, D.C.

Describes the alterable conditions which control the drying rate including spacing and size of piles, type and height of foundations, dimension of crossers, spacing between boards, and the flaring of chimneys.

2637. Gaines, Edward M.
1962. *Improved system for grading ponderosa pine and sugar pine lumber logs in trees.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 75, 21 p., illus. Berkeley, Calif.

Concepts behind the system are discussed together with suggestions for using the grades and a review of how they were developed.

2638. Gaines, Edward M.
1964. *Pocket guide to the improved grading system for ponderosa pine and sugar pine saw logs in trees.* 52 p., illus. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The log-grading system reported in Tech. Paper 75(1962) is presented in abbreviated form, with sketches to illustrate problems that one may encounter in using the grades.

2639. Gaines, Edward M.
1965. *Log and tree quality concepts.* Soc. Am. For. Proc. 1964:162-165.
Describes new opportunities for attacking the most complex problems of tree and log quality, and for broader application of quality information by use of computers.

2640. Garland, Hereford, and Lois Marion.
1942. *California manzanita for smoking pipes.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 19, 4 p. Berkeley, Calif.
This article discusses the range, methods of extraction, manufacturing, and extent of the industry in California.

2641. Garland, Hereford, and Lois Marion.
1960. *California manzanita for smoking pipes.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 53, 12 p., illus. Berkeley, Calif.
Discusses use of briarwood for pipes, and presents historical background, describes manzanita and range of burl-forming species, and outlines extraction and processing of burls into rough pipe blocks.

2642. Gerhards, C. C.
1964. *Limited evaluation of physical and mechanical properties of Nepal alder grown in Hawaii.* U.S. Forest Serv. Forest Prod. Lab. Rep. FPL-036, 9 p., illus.
Evaluates Nepal alder for shrinkage, strength in bending, and hardness, and compares it to the same species grown in India and to such species as aspen, ponderosa pine, and red alder.

2643. Gerhards, C. C.
1965. *Physical and mechanical properties of saligna eucalyptus grown in Hawaii.* U.S. Forest Serv. Forest Prod. Lab. Res. Paper FPL-23, 12 p., illus.
In comparison with wood of the same species grown in Australia, saligna eucalyptus grown in Hawaii was lower in density, shrinkage, and compressive strength parallel to grain, and was about equal in strength in bending and shear, but was stiffer.

2644. Gerhards, C. C.
1966. *Physical and mechanical properties of blackbutt eucalyptus grown in Hawaii.* U.S. Forest Serv. Forest Prod. Lab. Res. Paper FPL-65, 8 p., illus.
Reports that this wood is heavy, very strong in bending and compression, hard and exceedingly stiff, and its shrinkage is very large.

2645. Gerhards, C. C.
1966. *Physical and mechanical properties of Molucca albizzia grown in Hawaii.* U.S. Forest Serv. Forest Prod. Lab. Res. Paper FPL-55, 9 p., illus.
Finds the species to be light in weight, moderately weak in bending and compressive strength, moderately soft, and moderately limber, but somewhat above average in those properties for its density.

2646. Gerhards, C. C.
1967. *Physical and mechanical properties of 'Norfolk-Island-pine' grown in Hawaii.* U.S. Forest Serv. Forest Prod. Lab. Res. Paper FPL-73, 8 p., illus. U.S. Forest Prod. Lab., Madison, Wis.
The wood of this species is moderately heavy, moderately strong in both bending and compressive strength, stiff, and moderately hard.

2647. Gruenewald, F. A.
1939. *Preliminary statement of production of lumber, lath, and shingles in California, 1938.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 12, 2 p. Berkeley, Calif.
Gives a preliminary statement based on returns from the lumber census conducted by the Forest Service for the Bureau of the Census.

2648. Gruenewald, F. A.
1940. *Preliminary statement on production of lumber and other timber products in California, 1939.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 13, 2 p. Berkeley, Calif.
See item 2647 above.

2649. Gruenewald, F. A.
1941. *Preliminary statement of production of lumber, lath, and shingles in California, 1940.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 15, 2 p. Berkeley, Calif.
See item 2647 above.

2650. Harpole, George B.
1969. *Wood products in Hawaii . . . consumption, production, and trade.* USDA Forest Serv. Res. Note PSW-198, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Hawaii's wood products manufacturing industry may some day support the production of a volume of wood products well above the level of present day demands.

2651. Harpole, George B.
1970. *Opportunities for marketing Hawaii timber products.* USDA Forest Serv. Res. Paper PSW-61, 33 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Concludes that local and United States mainland markets could support an expanding Hawaii wood products industry.

2652. Harpole, George B., and H. Edward Dickerhoof.
1971. *Floor foundations: preferences of architects and builders in six southwestern United States markets.* USDA Forest Serv. Res. Paper PSW-74, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
More than 60 percent of the architects and builders queried would consider using an underfloor plenum system for heating and cooling.

2653. Harpole, George B., and H. Edward Dickerhoof.
1971. *Floor foundations, preferences of new home buyers in six Southwestern United States markets.* USDA Forest Serv. Res. Paper PSW-73, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Protection from termites, expected ease of reselling the home, and previous knowledge or experience were the most frequently cited factors influencing a preference for one floor system over another.

2654. Harpole, George B.
1971. *A simple technique to increase profits in wood products marketing.* USDA Forest Serv. Res. Note PSW-242, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes how a transportation model can be used to solve a number of optimization problems in the marketing of wood products.

2655. Harpole, George B.
1973. *Lumber and plywood used in California apartment construction, 1969.* USDA Forest Serv. Res. Note PSW-279, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Excluding wood mouldings, doors, cabinets, and shelving, an average 4.85 board feet of lumber and 2.03 square feet (3/8 inch) of plywood per square foot of floor area were used.

2656. Harpole, George B.
1973. *A marketing information system for the wood products manufacturer.* For. Prod. J. 23(11):11-15, illus.
Values of relative marketing efficiency and price variances are determined by calculating the accounting differences between the average realization derived from the elements in the marketing mix.

2657. Hill, C. L.
1924. *Study of air seasoning of lumber in California.* Timberman 25(9):50-51.
Describes the conditions and contingencies in the air drying of lumber and makes recommendations for corrective measures.

2658. Hill, C. L.
1927. *What forest waste means to the railways.* Pacific Railway Club Proc. 11(6):3-9.
Discusses reducing waste in production and use, forewarns against forest decimation without renewal and lends support to a bill for the extension and correlation of forest research.

2659. Hill, C. L.
1928. *The utilization of logging and sawmill waste, with special reference to pulp and paper.* Calif. J. Dev. 18(2):5-7, 25-28.
Discusses the mechanical and chemical utilization of wood waste including the manufacture of pulp, paper, rayon, and ethyl alcohol, and states that great savings can be attained by better air seasoning and kiln drying and by the extension of remanufacture at primary lumber producing plants.

2660. Hill, C. L.
1929. *Heptane from California pine trees.* Forest Worker 5(6):6.
Heptane produced by distilling the resin of Jeffrey and Digger pines has an advantage over that obtained from petroleum in the ease and cheapness of its recovery.

2661. Hill, C. L.
1930. *California lumber cut for 1929 shows increase instead of prophesied decrease.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 1, 2 p. Berkeley, Calif.
An increase of 5.6 percent was entirely due to the pine region since the redwood region showed a slight decrease in this year's production.

2662. Hill, C. L.
1930. *Lumber cut of California and Nevada, 1929.* Timberman 31(12):66.
An increase of 5.6 percent was due entirely to the pine region since the redwood region recorded a 1.3 percent reduction in cut.

2663. Hill, C. L.
1930. *Why California lumber cut for 1929 shows increase instead of prophesied decrease.* Pacific Purchaser 12(12):16-17.

An increase over that of the previous year of 5.6 percent is accounted for by the net excess of 23 new mills and of 18 mills operating in 1929 but idle in 1928.

2664. Hill, C. L.
1938. *A new way to get longer-lived fence posts.* Farm Bur. Monthly (Tulare County) 18(6):24.
Outlines a process of applying zinc chloride to fence posts which makes cheap woods last as long as the most durable ones.

2665. Hill, C. L.
1938. *Seasoning manzanita wood.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 9, 5 p. Berkeley, Calif.
Describes several alternative methods including air drying, chemical seasoning, and other preparations to be used with manzanita when kiln drying is impossible.

2666. Hornibrook, E. M., and W. R. Howden.
1965. *Top utilization of timber cut in California, 1964.* U.S. Forest Serv. Res. Note PSW-85, 9 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Factors affecting top utilization are largely related to the condition of old-growth timber stands currently harvested and are independent of ownership and subregion.

2667. Jackson, Willard L.
1962. *Guide to grading defects in ponderosa and sugar pine logs.* 34 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Presents current knowledge on the identification, definition, and significance of surface irregularities visible on ponderosa pine and sugar pine logs.

2668. Jemison, George M.
1955. *The forester and wood utilization.* North. Calif. Sect. Soc. Am. For. Proc. 1954:1-5.
Describes interdependence of forest management and forest products industries.

2669. Johnson, R. P. A., and M. R. Brundage.
1934. *Properties of white fir and their relation to the manufacture and uses of the wood.* USDA Tech. Bull. No. 408, 77 p. U.S. Gov. Print. Off. Washington, D.C.
Presents information on seasoning, grades, and influence of substandard sizes on strength and serviceability to help overcome prejudices against the marketing of *Abies concolor.*

2670. Josephson, H. R.
1935. *The forests and the lumbering industries of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 5, 6 p. Berkeley, Calif.
Discusses the composition, distribution, ownership, and utilization of forests in California concluding with a comment on the depletion of forest resources.

2671. Josephson, H. R.
1935. *Trends in California lumber requirements.* Pacific Retail Lumberman 2(7):7-8.
Per capita lumber requirements are steadily decreasing because of changes in type of buildings, substitute materials, and methods of construction.

2672. Josephson, H. R.
1935. *Wood consumption and secondary wood-using industries of California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 4, 3 p. Berkeley, Calif.
The average consumption during the decade 1920-1930 was about 750 board feet per capita; the most importnat use was in building construction, secondary users were furniture and box factories.

2673. Josephson, H. R.
1937. *Lumber production and consumption in California, 1920-1934.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 13, 5 p. Berkeley, Calif.
Presents graphs and charts indicating the source of lumber used and the distribution of lumber produced during the years 1920-1934.

2674. Kasile, Joseph D.
1962. *Wood charcoal production in California in 1961.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 210, 5 p., illus. Berkeley, Calif.
Production amounted to 5410 tons with the 103 operating kilns producing at only 24 percent of their potential annual capacity.

2675. LeBarron, Russell K.
1964. *Forest products harvested in Hawaii—1963.* U.S. Forest Serv. Res. Note PSW-51, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Compared to 1960, the total quantity of material declined but the total value increased for the output of primary forest products.

2676. MacKenzie, Kenneth D., and George Frazier.
1966. *Applying a model of organization structure to the analysis of a wood products market.* Manage. Sci. 12(8):B-340—B-352.
Outlines the use of a set theoretical model of organizations in the study of complex market organizations and its mathematical development.

2677. May, Richard H., and A. Simontacchi.
1947. *Production of lumber and other sawed products in California and Nevada, 1946.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 55, 9 p. Berkeley, Calif.
The pine region mills more than made up for the redwood region strike in pushing the lumber production in California for 1946 beyond all previous records.

2678. May, Richard H.
1948. *Recent trends of lumber production in California.* Timberman 49(5):56, 58, 60.
Pines have formed a decreasing proportion of the annual cut, Douglas-fir and true firs show an increase, redwood has maintained a constant relative position, and the number of active sawmills has shown an increase.

2679. May, Richard H., and A. Simontacchi.
1949. *Production of logs and bolts for plywood, veneer, pulpwood and cooperage in California, 1948.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 63, 5 p. Berkeley, Calif.
Gives tables listing the comparison of log production for each commodity by region, species, and county origin.

2680. May, Richard H.
1951. *Production of logs and bolts for plywood, pulp, container veneer, shingles, cooperage, poles, and piling in California, 1950.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 79, 6 p. Berkeley, Calif.
Surveys wood using industries at the request of the National Production Authority.

2681. May, Richard H.
1952. *Forest products used in mines in California and Nevada, 1950.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 15, 8 p. Berkeley, Calif.
Surveys the mining industry for use of timbers and lumber.

2682. May, Richard H.
1952. *Lumber production in California and Nevada—1951.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 15, 14 p. Berkeley, Calif.
Preliminary survey conducted by the California Forest and Range Exp. Stn. for the Bureau of the Census.

2683. May, Richard H.
1952. *Utilization of peeler logs.* Timberman 53(4):100.
Lath log utilization improved over the period 1942-1951.

2684. May, Richard H.
1952. *Wood used in manufacture in California in 1948.* Calif. Lumber Merchant 30(16):42, 44.
Presents statistics for wood use by species and product.

2685. May, Richard H.
1953. *A century of lumber production in California and Nevada.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 20, 33 p. Berkeley, Calif.
Presents statistics on California lumber production for the period 1849 to 1951, compiled in cooperation with the Bureau of the Census and the Department of Commerce.

2686. May, Richard H.
1953. *Timber production in the redwood region—1942 to 1951.* Redwood Reg. Logging Conf. Bull. 15th Annu. Conf. and Equip. Show. May 21-23, 1953:16-17.
Redwood lumber production increased three-fold during the decade.

2687. May, Richard H.
1954. *Output of forest products in California, 1952.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 23, 10 p. Berkeley, Calif.
Summarizes output of forest products in California by principal products, species, and region of production.

2688. May, Richard H., and L. N. Ericksen.
1955. *Wood residue from primary wood-using industries in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Paper 13, 15 p., illus. Berkeley, Calif.
Presents statistics from a survey of sawmills and plywood plants showing amount of wood residue produced, amount used and unused, and concentration areas where unused residue could supply raw material for new pulp industries.

2689. May, Richard H.
1956. *Wood leftovers could mean new industries.* Ukian News, Logging Ed. May 1956, Sec. 3:5, 8.
Presents statistics on logging and milling residues in the redwood region and points out opportunities for using this material for fiber production.

2690. May, Richard H., and H. L. Baker.
1957. *Lumber production in California, 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 30, 15 p., illus. Berkeley, Calif.
Reports that lumber production reached a new high and presents data on lumber production by species, counties, and mill-size classes.

2691. May, Richard H.
1957. *Production and plant receipts of veneer logs in California, 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 27, 7 p., illus. Berkeley, Calif.
Reports the highlights of a survey of peeler log receipts at veneer manufacturing plants in California and of logs shipped out of state.

2692. May, Richard H.
1957. *Wood charcoal in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 28, 12 p., illus. Berkeley, Calif.
Reports substantial increase in charcoal production and presents the history of charcoal operations in California and data on cordwood prices, charcoal prices, kiln capacity, and other pertinent facts.

2693. May, Richard H.
1957. *Wood receipts by fiber and board plants in California during 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 29, 4 p., illus. Berkeley, Calif.
Emphasizes increased use of wood chips as raw material.

2694. May, Richard H.
1958. *Development of the veneer and plywood industry in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 34, 26 p., illus. Berkeley, Calif.
The boom in both industries began after World War II with expansion into Douglas-fir, hitherto undeveloped.

2695. May, Richard H.
1958. *One-fifth fewer sawmills active in California in 1957.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 139, 3 p. Berkeley, Calif.
The business recession of 1957 reduced the number of active sawmills, with reduced activity most noticeable in the smallest sizes of mills.

2696. May, Richard H.
1958. *Output of split products in California, 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 33, 9 p., illus. Berkeley, Calif.
Output of split fence posts, grape-stakes, and similar products in California amounted to 21,433,000 board-feet of the product, with redwood by far the leading species used and Humboldt and Mendocino the leading counties.

2697. May, Richard H.
1958. *Output of timber products in California, 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 35, 35 p., illus. Berkeley, Calif.
Gives details for major products, especially sawlogs which comprise 82 percent of total output and 91 percent of roundwood output, and shows production by species and county in appendix tables.

2698. May, Richard H.
1958. *The production of poles, piling, and mine timbers in California, 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 32, 6 p. Berkeley, Calif.
Pole production increased 250 percent in California from 1952 to 1956, far offsetting small decreases in piling and mine timber production over the same period.

2699. May, Richard H.
1958. *Production of shingles and sawed shakes in California, 1956.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Forest Surv. Rel. 31, 7 p., illus. Berkeley, Calif.
Almost 36,000 squares of shingles and shakes were sawed in 26 mills in 1956, continuing a decline evident since about 1947.

2700. May, Richard H.
1960. *Lumber production in California and Nevada, 1952-1957.* Pacific Southwest Forest and Range Exp. Stn. Forest Surv. Rel. 37, 12 p., illus. Berkeley, Calif.
A continuation of the lumber production statistics previously reported in Forest Surv. Rel. No. 20, *A century of lumber production in California and Nevada.*

2701. McDonald, Philip M.
1973. *Incense-cedar . . . an American wood.* U.S. Dep. Agric. FS-226, 7 p., illus.
Summarizes the wood characteristics of this species and describes its principal uses.

2702. Mirov, N. T.
1930. *Turpentining experiments with western yellow pine in northern California.* J. For. 28(4):521-532.
Experiments show that mature trees yielded much more oleoresin than overmature trees, the Jerome Mill area showed the best rate of growth and the highest yield of oleoresin, and the Sugar Hill area had the smallest growth rate and the lowest oleoresin yield.

2703. Mirov, N. N.,and E. F. Kimbrough.
1952. *Sulfuric acid increases yield of gum in ponderosa pine.* J. For. 50(2):132.
Acid treatment increased gum yield 30 percent.

2704. Muerle, G. F., and Ezra M. Hornibrook.
1966. *Timber harvest in California, 1962.* U.S. Forest Serv. Res. Bull. PSW-2, 29 p. Pacific Southwest

Forest and Range Exp. Stn., Berkeley, Calif.
California's timber harvest was down only 21 percent from the 1956 level despite a 57 percent reduction in the number of active sawmills and a 26 per cent increase in the number of plants peeling logs for veneer and plywood.

2705. Nelson, Robert E., and Ezra M. Hornibrook.
1962. *Commercial uses and volume of Hawaiian tree fern.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn., Tech. Paper 73, 10 p., illus. Berkeley, Calif.
A volume table for estimating the cubic contents of individual fern trunks is given, together with preliminary information on the abundance, concentration, and total volume of this resource.

2706. Nelson, Robert E.
1962. *Forest products harvested in Hawaii in 1958 and 1960.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 71, 3 p. Berkeley, Calif.
Summarizes survey data from the Hawaii Forestry Division, points out significant differences in production for the two years, and attempts to account for the differences.

2707. Newport, Carl A., and Joe Leach.
1959. *A method for the application of change in grade factors to individual logs—an IBM 650 Program.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 41, 9 p. Berkeley, Calif.
Describes a machine method of converting "rough green" lumber recovery to "surfaced dry" lumber recovery, computing the total volume of surfaced dry lumber recovered, and computing the value of each study log under any given surfaced dry lumber grade price situation.

2708. Newport, Carl A., and Elliot L. Amidon.
1961. *Lumber grade and value performance of young growth ponderosa pine logs at the Challenge Experimental Forest.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 55, 14 p., illus. Berkeley, Calif.
Reports the volumes of different lumber grades recovered from 500 logs and shows tables of amounts by diameter and grade of logs.

2709. Newport, Carl A., and William G. O'Regan.
1963. *An analysis technique for testing log grades.* U.S. Forest Serv. Res. Paper PSW-3, 16 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
This analytical technique provides a means of comparing two or more grading systems or a proposed change with the system from which it was developed.

2710. O'Regan, William G., and N. E. Savin.
1964. *On log-grading and timber appraisal.* Forest Sci. 10(2):239-240.
The problem of predicting lumber grade output and/or value is placed in the framework of multi-variate multiple regression and prediction.

2711. Peters, C. C., and F. J. Lutz.
1966. *Some machining properties of two wood species grown in Hawaii—Molucca albizzia and Nepal alder.* U.S. Forest Serv. Forest Prod. Lab. Res. Note FPL-0117, 17 p., illus.
Compares the machining properties of the two species with those of several mainland hardwoods of about the same specified gravity and finds that both species should be suitable for core stock—provided sufficient straight grained material is available.

2712. Pong, W. Y., and Harvey H. Smith.
1962. *Change of grade and volume of Douglas-fir shop and better lumber during kiln drying.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 70, 12 p. Berkeley, Calif.
Reports more degrade in higher lumber grades as compared to lower lumber grade, and in wide, thick lumber as compared to narrow thin lumber.

2713. Sanford, Burnett.
1930. *Log utilization.* J. For. 28(3):351-353.
Discusses three types of waste, namely material, labor, and capital, and how these affect timber marketing and profit making.

2714. Schimke, Harry E.
1965. *Chipping of thinning slash on fuel-breaks.* U.S. Forest Serv. Res. Note PSW-58, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A heavy stand of conifer saplings was thinned, piled, and chipped at costs of $9.66 per ton of dry material, and $11.81 for green slash.

2715. Skolmen, Roger G.
1961. *Forests and forest products in Hawaii—past, present, and future.* South. Lumberman 203 (2537):158-161, illus.
Relates the history of forest tree planting in Hawaii and appraises the potential timber production on one-half million acres of commercial forest land.

2716. Skolmen, Roger G., and Harvey H. Smith.
1962. *Drying of silk-oak in Hawaii.* U.S. Forest Serv.

Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 65, 11 p., illus. Berkeley, Calif.
Air drying was more rapid and degrade less in lumber piles spaced at 5 feet compared to those spaced at 1 foot whereas roofing the piles had no influence on drying rate or degrade due to drying.

2717. Skolmen, Roger G.
1962. *Treating costs and durability tests of Hawaii-grown wood, posts treated by double-diffusion.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 198, 5 p.
The cost of debarking and chemical treatment are determined and preliminary results of exposure tests are reported.

2718. Skolmen, Roger G.
1963. *A durability test of wood posts in Hawaii—first progress report.* U.S. Forest Serv. Note PSW-34, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Exposure of double-diffusion-treated and untreated posts of Hawaii-grown wood shows that untreated 3- to 5-inch posts of 10 species will last from less than a year to 2½ years, depending on species.

2719. Skolmen, Roger G.
1963. *Robusta eucalyptus wood, its properties and uses.* U.S. Forest Serv. Res. Paper PSW-9, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports present use in both rough construction and interior finish and summarizes information from research which could lead to expanded use.

2720. Skolmen, Roger G.
1963. *Wood density and growth of some conifers introduced to Hawaii.* U.S. Forest Serv. Res. Paper PSW-12, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Specific gravity and growth characteristics for 14 conifers under several site conditions were compared.

2721. Skolmen, Roger G.
1964. *Air-drying of robusta eucalyptus lumber.* U.S. Forest Serv. Res. Note PSW-49, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
An air-drying study of 4/4 robusta eucalyptus lumber in Hilo, Hawaii, indicated that during typical summer weather it can be dried to below 20 percent moisture content in 2½ months.

2722. Skolmen, Roger G., and Charles C. Gerhards.
1964. *Brittleheart in robusta eucalyptus logs.* Forest Prod. J. 14(12):549-554, illus.
Brittleheart can be segregated from normal wood on the basis of heartwood color contrast, end grain characteristics, and visible compression failures, but only at the expense of including some normal wood with the brittleheart.

2723. Skolmen, Roger G.
1965. *A durability test of wood posts in Hawaii—second progress report.* U.S. Forest Serv. Res. Note PSW-91, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Exposure of double-diffusion treated and untreated round posts showed that untreated 3- to 5-inch posts will last from less than a year to 3 years, depending on species and that, except for three species, the treatment did not afford a service life sufficiently longer to justify using it.

2724. Skolmen, Roger G.
1965. *Water spray protects stored logs in Hilo, Hawaii.* U.S. Forest Serv. Res. Note PSW-84, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Spraying stored robusta eucalyptus logs continuously with water greatly reduced damage from end splitting, stain, and insect attack.

2725. Skolmen, Roger G.
1967. *Heating logs to relieve growth stress.* Forest Prod. J. 17(7):41-42, illus.
Over half the stress contained in 6- to 8-inch, 5-year-old *Eucalyptus saligna* logs was relieved by boiling them in water for 24 hours.

2726. Skolmen, Roger G.
1967. *Specific gravity and shrinkage of Elaeocarpus joga wood from Guam.* U.S. Forest Serv. Res. Note PSW-163, 2 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
With a specific gravity of 0.433 and a characteristic of low shrinkage, this hardwood has excellent potential as a general utility wood for local use on Guam.

2727. Skolmen, Roger G.
1968. *Natural durability of some woods in Hawaii . . . preliminary findings.* U.S. Forest Serv. Res. Note PSW-167, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Six imported and eight Hawaii-grown species are being tested for their natural resistance to decay and insect attacks with damage to the heartwood having progressed far enough to allow comparisons.

2728. Skolmen, Roger G.
1968. *Preservatives extend service life of ohia and*

robusta posts. U.S. Forest Serv. Res. Note PSW-171, 2 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Posts of both species, treated with chromated copper arsenate or pentachlorophenol with a water repellent in mineral spirits, are all still sound after 5 years.

2729. Skolmen, Roger G.
1968. *Wood of koa and black walnut similar in most properties.* U.S. Forest Serv. Res. Note PSW-164, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Koa, a native hardwood of Hawaii, is quite similar to black walnut in all technical properties and is suitable for the same uses as black walnut.

2730. Skolmen, Roger G.
1970. *Lumber grade recovery from Hawaii-grown robusta eucalyptus logs.* USDA Forest Serv. Res. Note PSW-204, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
The average robusta log yielded 44 percent no. 1 common and better lumber.

2731. Skolmen, Roger G.
1971. *A durability test of wood posts in Hawaii . . . third progress report.* USDA Forest Serv. Res. Note PSW-260, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Except with two coniferous species, the preservative treatment did not lengthen service life enough to be judged worthwhile.

2732. Skolmen, Roger G.
1971. *Processing Hawaii-grown robusta eucalyptus from logs into furniture.* 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports evaluation by experienced people, that robusta eucalyptus is usable, but is not a desirable wood for use in furniture manufacture.

2733. Skolmen, Roger G.
1972. *Paintability of four woods in Hawaii.* USDA Forest Serv. Res. Note PSW-267, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
After 7 years, all of the paint combinations being tested except self-primed latex are showing some failure on all wood species being tested except Australian toon.

2734. Skolmen, Roger G.
1972. *Specific gravity variation in robusta eucalyptus grown in Hawaii.* USDA Forest Serv. Res. Paper PSW-78, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Mean specific gravity was 0.603, but the range between individual samples was 0.331 to 0.869 among 50 trees and within one cross section was 0.357 to 0.755.

2735. Skolmen, Roger G.
1973. *Characteristics and amount of brittleheart in Hawaii-grown robusta eucalyptus.* Wood Sci. 6(1):22-29, illus.
Brittleheart—brash wood near the pith—was found to make up 18.5 percent of the board foot volume of 50 *Eucalyptus robusta* trees.

2736. Skolmen, Roger G.
1973. *Pressure treatment of robusta and ohia posts . . . final report.* USDA Forest Serv. Res. Note PSW-285, 2 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Round posts pressure treated with two preservatives so far have lasted more than twice as long as untreated posts; all but one treated post are still sound after 10½ years.

2737. Skolmen, Roger G.
1974. *Lumber potential of 12-year-old saligna eucalyptus trees in Hawaii.* USDA Forest Serv. Res. Note PSW-288, 7 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Lumber was predominantly of low grade, but had lower average density and thus was more desirable than wood from older trees.

2738. Skolmen, Roger G.
1974. *Natural durability of some woods used in Hawaii . . . results of 9½ years' exposure.* USDA Forest Serv. Res. Note PSW-292, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Reports the decay and insect resistance of eight Hawaii-grown and seven imported species in an in-the-ground stake test and above-the-ground post-rail unit test over a 9½ year period.

2739. Skolmen, Roger G.
1974. *Some woods of Hawaii . . . properties and uses of 16 commercial species.* USDA Forest Serv. Gen. Tech. Rep. PSW-8, 30 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes in detail tree and log characteristics and wood properties of 16 of Hawaii's more important commercial species.

2740. Skolmen, Roger G.
1975. *Shrinkage and specific gravity variation in robusta eucalyptus wood grown in Hawaii.* USDA

Forest Serv. Res. Note PSW-298, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Shrinkage and specific gravity of plantation-grown *Eucalyptus robusta* wood increased as distance from the pith and as height in the tree increased.

2741. Smith, Harvey H.
1949. *Seasoning California black oak.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 62, 8 p. Berkeley, Calif.
Discusses air-drying and kiln-drying techniques indicating that California black oak, cut into thin sizes, can be dried in a relatively short time without drying effects.

2742. Smith, Harvey H.
1950. *Check list for inspection of lumber dry kilns.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 69, 3 p. Berkeley, Calif.
Includes a check list which may be used as a guide in making routine inspections of buildings and equipment.

2743. Smith, Harvey H.
1950. *Further experiments in seasoning California black oak.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 75, 11 p. Berkeley, Calif.
Concludes that California black oak can be seasoned by well established, conventional methods.

2744. Smith, Harvey H.
1951. *Direct-heat lumber dry kilns.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Misc. Paper 4, 5 p. Berkeley, Calif.
Describes the advantages and disadvantages of small kilns powered by gasoline or diesel engines or electric motors.

2745. Smith, Harvey H.
1952. *Utilization of western hardwoods.* J. Forest Prod. Res. Soc. 2(3):52-54.
Of nine species tested, four (tanoak, madrone, chinquapin and laurel) were difficult to season and five (red alder, Oregon ash, California black oak, Oregon white oak, and Oregon maple) were easily seasoned using techniques developed in Mississippi.

2746. Smith, Harvey H.
1954. *Seasoning California hardwoods.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 5, 8 p. Berkeley, Calif.
Presents results of experimental air drying and subsequent kiln drying of California laurel, madrone, tanoak, and golden chinkapin.

2747. Smith, Harvey H.
1956. *Improved utilization of western hardwoods by modern drying.* Forest Prod. J. 6(3):121-124.
Application of modern drying practices could greatly increase the utilization of western hardwoods.

2748. Smith, Harvey H., and Charles P. Berolzheimer.
1957. *Air drying of incense-cedar: Tests under summer conditions in California.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 123, 10 p., illus. Berkeley, Calif.
During the favorable summer weather, 3-inch incense-cedar squares dried faster and with less drying than wider 3-inch thick planks with pile spacing and position in the pile having no effect on drying rate or incidence of defects.

2749. Smith, Harvey H., and Charles P. Berolzheimer.
1959. *Air drying of incense-cedar: Tests under winter conditions in California.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 38, 13 p., illus. Berkeley, Calif.
Pile spacing and width of material had little effect on drying rate of pencil stock, but type of wood and green moisture content had pronounced effects.

2750. Smith, Harvey H., and John R. Dittman.
1960. *Drying rate of white fir by segregations.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 168, 10 p., illus. Berkeley, Calif.
The green moisture content of each type of wood is the most important single factor in drying white fir to a uniform final moisture content by today's commercial schedules.

2751. Smith, Harvey H., and John R. Dittman.
1960. *Effect of solid storage on the uniformity of final moisture content of kiln dried lumber.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 162, 5 p., illus.
One week of bulk or solid storage had a pronounced effect on moisture distribution within individual pieces with areas of high moisture becoming greatly reduced.

2752. Smith, Harvey H., and John R. Dittman.
1960. *The segregation of white fir for kiln drying.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 167, 6 p., illus. Berkeley, Calif.
Drying time varies in a ratio close to 2-4-8 for cork-, sap-, and sinker-type wood respectively, and indicates the need for accurate segregation to achieve a small range of final moisture content.

2753. Smith, Harvey H.
1960. *Wood quality studies to guide Hawaiian forest*

industries. U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Misc. Paper 48, 19 p., illus. Berkeley, Calif.
End use requirements were studied to help select species of island-grown timber for further research on wood properties and to help recommend the kinds of studies needed to determine their suitability for certain end uses.

2754. Smith, Harvey H.
1961. *Recommendations for drying California black oak.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 62, 19 p., illus. Berkeley, Calif.
Suggests predrying to 20 percent moisture content in air-drying yard or forced-air drier, and then final kiln drying to 6 to 8 percent.

2755. Smith, Harvey H., and Roy H. Baechler.
1961. *Treatment of Hawaiian grown wood posts by the double-diffusion wood preservation process.* U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Res. Note 187, 8 p. Berkeley, Calif.
Of twelve species selected to measure their treatability by the double-diffusion method, several species suitable for posts and available in good supply were found to take the treatment well.

2756. Smith, Harvey H.
1966. *Experimental design in dry kiln research.* Proc. 18th Annu. Meet. West. Dry Kiln Clubs:29-35.
Describes the established research methods of design and planning used in a study of the drying of incense-cedar pencil slats.

2757. U.S. Forest Service, California Forest and Range Experiment Station.
1942. *Stumpage and log prices in California, preliminary statistics for 1941.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Tech. Note 20, 3 p. Berkeley, Calif.
Preliminary statement based on returns from the lumber census conducted for the Bureau of the Census.

2758. U.S. Forest Service, California Forest and Range Experiment Station.
1943. *Preliminary estimate of production of lumber, lath, and shingles in California, 1942.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 29, 5 p. Berkeley, Calif.
See item 2757 above.

2759. U.S. Forest Service, California Forest and Range Experiment Station.
1943. *Stumpage and log prices in California by species and type of sale, preliminary statistics for 1942.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 30, 5 p. Berkeley, Calif.
See item 2757 above.

2760. U.S. Forest Service, California Forest and Range Experiment Station.
1944. *Production of lumber, lath, and shingles in California, 1943.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 40, 4 p. Berkeley, Calif.
See item 2757 above.

2761. U.S. Forest Service, California Forest and Range Experiment Station.
1944. *Stumpage and log prices in California by species and type of sale.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 38, 2 p. Berkeley, Calif.
See item 2757 above.

2762. U.S. Forest Service, California Forest and Range Experiment Station.
1945. *Production of lumber, lath, and shingles in California and Nevada, 1944.* U.S. Forest Serv. Calif. Forest and Range Exp. Stn. Res. Note 45, 5 p. Berkeley, Calif.
See item 2757 above.

2763. Vaux, Henry J., and R. H. May.
1948. *Use of wood in new housing in California—1946.* Calif. Lumber Merchant 27(9):30-33.
Presents data on the types of construction, dwelling size and variations in wood use.

2764. Vaux, Henry J., and R. H. May.
1949. *A regional study of lumber use in housing.* J. For. 47(4):260-264.
Wood use was examined in 3603 new residential buildings erected in California during 1946 and estimates were made of the average volume of lumber required per dwelling unit, and of the effects of kind of dwelling, type of construction, dwelling size, design, and trends in consumption on such use.

2765. Weber, John H., George D. Frazier, and Kenneth D. MacKenzie.
1965. *Wood, style and innovation in the Los Angeles furniture industry.* West. Furniture Manuf. 20(1):20-30.
Designers, manufacturers, and retailers forecast a continued trend toward more wood in home furnishings, office furniture, and industrial and commercial furniture and less wood in institutional and school furniture.

2766. Whitesell, Craig D., Bruce J. Zobel, and James Roberds.

1966. *Specific gravity and tracheid length of loblolly pine in Maryland and Delaware.* N.C. State Univ., Sch. For. Tech. Rep. 29, 11 p., illus.
Concludes that soil and growth characteristics measured had very little effect on specific gravity and tracheid length, although there was very large tree-to-tree variability.

2767. Wick, Herbert L.
1968. *Forest products harvested in Hawaii—1967.* USDA Forest Serv. Res. Note PSW-179, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
A survey of the primary forest products harvested in Hawaii for 1967 showed a 24 percent increase over the 1957 value.

2768. Zinnikas, John D.
1966. *The Pacific Basin market for wood products for military support activities.* U.S. Forest Serv. Res. Paper PSW-27, 6 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Finds that the military support activities in Hawaii use between 50 and 150 thousand board feet of lumber annually for which locally grown and produced hardwood lumber might be used.

2769. Zinnikas, John D., and R. Sidney Boone.
1967. *Markets for Hawaii hardwood lumber in new single-family houses on Oahu, Hawaii.* U.S. Forest Serv. Res. Paper PSW-41, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Total market for lumber in a new single-family house construction from 1965 to 1970 is estimated at between 18 and 23 million square feet of flooring, 28 and 36 million square feet of siding, and 7 and 9½ million square feet in cabinets.

2770. Zinnikas, John D., and R. Sidney Boone.
1967. *Requirements for new housing in Hawaii 1965-70 . . . a forecast.* U.S. Forest Serv. Res. Paper PSW-40, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
An estimated 44,300 new housing units are needed with new single-family houses expected to comprise between 20,000 and 26,000 of these units.

MANAGEMENT SCIENCES

2771. Bell, Frank C., Walter L. Graves, Malcolm W. Kirby, and others.
1968. *Size of Ranger District study.* 108 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Socio-technical systems framework was taken as a reference, but attempt was made to tie size more directly to its consequences on organizational effectiveness.

2772. Bell, Frank C.
1970. *An example of optimization techniques in land management: the Eldorado Model.* Colo. State Univ. Range Sci. Dep. Sci. Series 5:75-87.
This mathematical model, consisting of a matrix generator, linear programming, and report generator, uses optimization techniques to solve complex resource problems.

2773. Broido, A., R. J. McConnen, and W. G. O'Regan.
1965. *Some operations research applications in the conservation of wildland resources.* Manage. Sci. Ser. A, 11(9):802-814.
Indicates by examples some of the limited operations research work being done on wildland problems and calls attention to the ever increasing opportunity for more effort.

2774. Claxton, H. Dean, and Giuseppi Rensi.
1972. *An analytical procedure to assist decision-making in a government research organization.* USDA Forest Serv. Res. Paper PSW-80, 20 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.
Describes the characteristics that distinguish research from other forms of productive activities and the potential uses of a management information system for a government research organization.

2775. Davis, James B.
1968. *Why not PERT your next resource management problem?* J. For. 66(5):405-408, illus.
PERT—a critical path technique—has become a valuable management tool in both government and industry; but it has not been widely used in resource management, although it is adaptable to many problems.

2776. Davis, L. E., and E. S. Valfer.
1965. *Intervening responses to changes in supervisor job design.* Occup. Psychol. 39:3
A model of organizational and individual response to job design changes at any level of an organization was tested by means of a set of intervening-response variables and related response hypothesis.

2777. Davis, L. E., and E. S. Valfer.
1972. *Studies in supervisory job design.* In *The social*

technology of organization development, p. 162-176, illus. W. Warner Burke and Harvey A. Hornstein, eds.: NTL Learning Resour. Corp., Fairfax, Va.

Describes studies designed to test the hypothesis that higher productivity and greater needs satisfaction will result from specifying the contents of the supervisor's job.

2778. Elsner, Gary H., Michael Travis, and Peter H. Kourtz.
1975. *Dynamic programming subroutines based on the Dijkstra algorithm for finding minimum cost paths in directed networks.* Inf. Rep. FF-X-51, 16 p. Ottawa, Can.

These basic subroutines have been applied in fire and recreation modeling problems and are useful in a wide variety of modeling efforts.

2779. Gould, Ernest M., Jr., and William G. O'Regan.
1965. *Simulation—a step toward better forest planning.* Harv. Forest Papers 13, 86 p., illus.

Suggests that simulation can be useful especially for comparing the probable outcome of forest management alternatives, includes a review of a simple forest operating unit model that is capable of further refinement, and describes a test problem.

2780. Kirby, Malcolm W.
1965. *Information explosion: A managerial challenge.* U.S. Forest Serv. Div. Admin. Manage. Notes 15:7-8.

An important effect of new computer-dominated information technology on management is to make a man-machine system out of what was principally a man system.

2781. Kirby, Malcolm W.
1965. *Optimum size of rented and owned passenger fleets.* Univ. Calif. Oper. Res. Center ORC 65-28, 41 p. Berkeley, Calif.

Describes a study to find the optimum pool size in which a pool of vehicles, rented or owned or both, serves the needs of a group of users.

2782. Kirby, Malcolm W., and Sherman J. O'Neill.
1965. *Vehicle repair: in-house or out?* U.S. Forest Serv. Div. Admin. Manage. Notes 16:26-28.

Reports on preliminary work to answer the question: When is it better to pay commercial garages for repairing vehicles, and when is it better to employ mechanics in your own shop?

2783. Kirby, Malcolm W.
1970. *Applied economics—tool box power of the management analyst.* U.S. Forest Serv. Manage. Notes 33:22-27, illus.

Presents a brief glimpse of some important, useful ideas from applied economics and application to management analysis.

2784. Kirby, Malcolm W.
1971. *Methodology of program budgeting on a National Forest: The Eldorado experience—Part A.* 60 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Details on mathematical model, computer package, sample reports, and other aspects of the annual budget model.

2785. Kirby, Malcolm W.
1971. *Methodology of program budgeting on a National Forest: The Eldorado experience. Part B.* 92 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Contains reproductions of Eldorado National Forest goals and objectives for both 1- and 5-year programs.

2786. Kirby, Malcolm W.
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periment Station. In *Proceedings Berkeley Symposium on Mathematical Statistics and Probability.* p. 459-463. Univ. Calif. Press, Berkeley, Calif.
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2899. Yerke, Theodor B., and Hilary D. Lent.
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2900. Yerke, Theodor B.
1970. *Computer support of the researcher's own documentation.* Datamation 16(2):75-77.
Discusses differences between the documentation aims of researchers, librarians, and operators of national indexing and abstracting services, and ways in which they influenced the design of FAMULUS, a personal documentation system.

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2902. Yerke, Theodor B.
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Forestry will have to take advantage of recent developments in information science research to handle the information requirements that new concepts in land management and new social demands on forestry are placing on managers and program planners.

2903. Yerke, Theodor B.
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represents the research branch of the Forest Service in California and Hawaii.

TREE FAILURES AND ACCIDENTS IN RECREATION AREAS:

A Guide to Data Management for Hazard Control

Lee A. Paine James W. Clarke

PACIFIC
SOUTHWEST
Forest and Range
Experiment Station

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

GENERAL TECHNICAL
REPORT PSW- 24

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1978

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LEE A. PAINE is a forest pathologist, stationed in Berkeley, studying problems in forest tree diseases, particularly in relation to evaluation and control of public hazard and safety in wooded recreation sites. He came to the Pacific Southwest Station from the Canadian Science Service in 1957. He holds bachelor's (1943) and master's (1947) degrees in forestry from the University of Idaho and a doctorate (1951) from the Swiss Federal Institute of Technology. **JAMES W. CLARKE** is a computer specialist in the Station's statistical services group. He joined the Forest Service in 1953 and has been at the Station since 1962.

Paine, Lee A., and James W. Clarke

1978. **Tree failures and accidents in recreation areas: A guide to data management for hazard control.** Gen. Tech. Rep. PSW-24, 30 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A data management system has been developed for storage and retrieval of tree failure and hazard data, with provision for computer analyses and presentation of results in useful tables. This system emphasizes important relationships between tree characteristics, environmental factors, and the resulting hazard. The analysis programs permit easy selection of subsets of data for examination of individual species, sites, and other categories of information. Use of this system allows site managers to control hazard at lower cost to both the site and the budget.

Oxford: 907.2:416:304(083.7)

Retrieval Terms: hazard trees; hazard reduction; recreation areas; safety standards; data management; computer programs.

INTRODUCTION

To managers of wooded recreation areas, the safety of the public and protection of site and property are major concerns. Injuries, fatalities, and high property losses occur each year as a result of tree failures on such sites. Complete prevention of accidents is usually not possible without sacrifice of the recreational values of such a site, but an acceptable level of safety can be achieved by modifying the expected losses associated with public occupancy. Hazard reduction can limit such losses to predefined levels consistent with site values and public welfare. Lack of permanent records, however, combined with misunderstanding of the influence of hazard components, has made effective hazard control very costly in the past. Today we have enough data on tree failures to permit most individual agencies to control hazard with predictable results at lower cost.

For a number of years, State and Federal agencies have been recording the details of failures and accidents within their jurisdiction. Many have used this information in their own planning and management, and have also provided copies of it for use in a nationwide research program undertaken by the U.S. Forest Service. The failure reports on which data have been submitted are patterned on U.S. Forest Service Form PSW 4600-3 (*fig. 1*). Generally, tree failures are reported only if they were large enough to inflict injury or property damage. Most of the terms used here have been defined previously,[1] but one or two should be emphasized.

A *tree failure* is the uprooting or breakage of any significant part of a tree, when the failure was not directly caused by logging or construction work.

Hazard, in this context, is the expected dollar loss that will result from mechanical failure of a particular tree during a specific time, such as one year. It depends, in part, on the probability that the tree will fail during a given period, and on the contingent probability that a target will be struck by the tree if it fails. Hazard can only exist, then, if there is a target of value which may be damaged by the failure. The targets under consideration are usually people, fixed or movable property, and agency site improvements. Loss from damage to the natural site or to the tree itself is not considered in this context.

Because all trees would fail in time, reduction of hazard must be effected by (1) removing part or all of the tree before failure, (2) excluding recreationists or limiting exposure (especially during high-risk periods), or (3) a reasonable combination of these actions. Managers have become increasingly aware of these control options and of the critical factors noted on the report form. Our analyses by species and locality have already begun to concentrate attention on the more dangerous situations. One result has been a consistent annual decrease in the proportion of failures which cause accidents.

In the course of our research on hazard, we have developed a group of computer programs for retrieval and analysis of desired information from the data submitted by cooperating agencies. This user's guide to the programs, in conjunction with the program tape, the coding manual, and the user's own data, will provide a manager with analyses that will greatly assist in identifying problems and in achieving economical control of hazard. During the past years, we have been able to prepare only a limited number of analyses for cooperating agencies. Now, almost any administrator or manager with access to a large computer can carry out his own analyses as needed.

Analyses produced with the data management system described in this manual will provide a manager with information on the relative frequency of failures and accidents, by species; the types of accidents and dollar losses; the classes of failure that have occurred most often; the defects that have most frequently led to failure; and the environmental factors that have triggered failures. In addition, data on diameter classes, time of day, month, site, elevation, and other factors normally recorded can be analyzed to determine their influence. Relations between class of failure, defect, and environmental factors are also available. Because this information can be related to specific areas, the hazard inspector can localize problems and allocate his time and priorities more effectively. The administrator, with a review of statistics for the over-all area, can recommend intensification of efforts where needed and can budget funds to meet defined goals. The site planner can identify those sites with high-risk species or size classes and advise managers to avoid or modify them before making heavy investments on inappropriate locations.

[1] Paine, Lee A. 1971. *Accident hazard evaluation and control decisions on forested recreation sites.* USDA Forest Serv. Res. Paper PSW-68, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

REPORT OF TREE FAILURE ①
(Mechanical break, collapse, or uprooting)

REPORTING AGENCY: ______________________ UNIT: ______________________

(A) Tree and stand

Species: ______________________
Approximate dbh of tree: __________ inches
Approximate age of tree: __________ years
Forest type: ______________________
Stand age class: ___ Overmature
___ Mature
___ Young-growth
___ All-age
Elevation of site: ______________________

(B) Class of mechanical failure

___ Upper bole (top half)
___ Lower bole
___ Butt (lower 6 feet)
___ Limb
___ Root, including uprooting

(C) Tree defect or fault leading to failure ②

___ Rot (trunk, limb, or root)
___ Sweep
___ Tree dead - snag
___ Fire wound
___ Leaning
___ Lightning wound
___ Mechanical wound
___ Cracks or splits
___ Fork or multiple top
___ Twin bole or basal fork
___ Dead top or branch
___ Widow-maker or hang-up
___ Canker, rust
___ Canker, mistletoe
___ Other: ______________________
___ Unknown or none

(D) Contributing factors

___ Wind
___ Snow
___ Erosion
___ Soil - saturation
___ Stream bank erosion
___ Shallow rooting
___ Tree striking tree
___ Other: ______________
___ Unknown or none

(E) Time and location of incident

Approximate hour: ______________
Month, year: ______________
County: ______________
State: ______________
Site open for public use: Yes ____ No ______

(F) Land ownership

___ Federal
___ State
___ Other public: ______________
___ Private
___ Public utility

(G) Site category

___ Established camp or picnic ground
___ Other established public use site ③
___ Volunteer site ④
___ Marked trail
___ Special use site ⑤
___ Roadside
___ Residence site ⑥
___ Other: ⑦ ______________
___ Urban

(H) Property or person directly affected

___ Agency
___ Recreationist
___ Forest industry
___ Permittee-Concessionaire
___ Other: ______________
___ Contractor
___ Public utility

(I) Consequences

___ Clean-up work required
___ Property damaged: ______________
Property loss estimate: $______________
___ Injuries (Do not give tree values)
___ Medical attention required
___ Fatalities

(J) Name of site: ⑧ ____
Comments: ____

Only failures of a size capable of inflicting some damage or injury should be reported. Minor limb failures should not be reported unless they were potentially dangerous. Do not report simple death of a tree or part of a tree unless it resulted in mechanical failure. Trees removed prior to failure should not be reported.

Forest Service Form PSW-4600-3 (Rev 6/75)

Figure 1—For data management, reports of tree failures and accidents are submitted on a form patterned after the U.S. Forest Service Form PSW-4600-3.

① A report should be made for:

(1) each tree failure involving property damage or bodily injury;

(2) each failure adjacent to permanent recreation facilities, home sites, or other locations where failures are a threat to property, and;

(3) each failure on recreation sites and other high use locations during the season of public use, whether or not the failure causes damage or injury.

② Check only those defects and contributing factors which lead to the actual failure.

③ Other established public use site: Winter sports, beaches, viewpoints, visitor centers, historical buildings, etc.

④ Volunteer site: Undeveloped site with concentrated public use.

⑤ Special use site: Resorts, service facilities, etc.

⑥ Residence site: Agency, private, or permittee-lessor.

⑦ Other: Wilderness area sites, open forest, etc.

⑧ Published analyses will not indicate the source of specific incidents.

If many failures occur in your area, reports may be limited to managed sites normally subject to inspection and hazard control. Where information is available, however, reports from volunteer and other noninspected sites will be of value.

NOTE: A SEPARATE FORM SHOULD BE COMPLETED FOR EACH INDIVIDUAL FAILURE. Inclusion of more than one failure on a report prevents correlation of data unless all details are identical.

Additional forms may be obtained from your headquarters or by writing to the following address:

Return to: Lee A. Paine
U.S.D.A. Forest Service
P.O. Box 245
Berkeley, California 94701

Commercial Phone: (415) 486-3158
FTS Phone: 449-3158

Thus, this data control system is a means of planning and monitoring hazard management programs. It delineates program modifications dictated by problem areas, species, or conditions, assists in selection of new recreation sites, and serves as a useful record in legal actions when accidents occur. Specifically, the data processing programs facilitate storage, editing, and retrieval of tree failure and accident data (species, class of failure, target, loss, etc.), and execution of analyses useful in hazard control management.

The programs and instructions are intended for recreation site managers and administrators with local or remote access to computers. Although a basic understanding of data coding and retrieval is assumed, use of the programs does not require specialized knowledge of computer programming or operation. The illustrations of program control cards, sample data cards, and sample output are given as they would be used on a Control Data 6600 computer[2] under a Scope operating system. A programmer or systems analyst should be able to modify them easily for use with other available equipment. Once the programs are made compatible with the local data processing system, the procedure for management of the data and use of the programs is essentially as described here.

Three of the programs in the system are available on tape; the fourth is listed in this guide and is available on cards. To obtain the programs, send a magnetic tape (1200- or 2400-foot reel) to Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701, Attention: Statistical Services. If your agency has previously submitted data to this Station, send a second tape and request a copy of the data.

In addition to the programs and the already existing data files, the coding manual[3] is needed so that new data files from the failure report forms can be established. Staff members of agencies and organizations which have not previously received a printout of the coding manual should request that it be included with the program tapes.

[2] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

[3] Paine, Lee A. *Coding hazardous tree failures for a data management system.* Gen. Tech. Rep. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif. Manuscript in preparation.

The basic procedure for use of these programs requires the following steps:

1. Pertinent data must have been collected (as in *fig. 1*).

2. Data must have been coded and punched on standard 80-column data cards as indicated in the coding manual.

3. Cards should be subjected to the ERROR CHECK program for detection of illegal punches.

4. Following any necessary corrections, the data must be added to any earlier data on a computer tape, using the WRITE program.

5. Accumulated data on the tape can then be subjected to selective analyses using the FAILURE programs. These programs provide summaries in one of seven standard tables. The FAILURE programs are flexible; groups of tree failures associated with specified environmental, geographic, organizational, and species characteristics may be studied as easily as a single group encompassing all reported failures for an agency.

6. As an option, data cards or listings of selected incidents may be re-created from the data tape using the PUNCH program. Cards produced by PUNCH may be used for editing and resubmission to a data tape, for special analyses, or for transmittal of data to other offices.

In this guide to the ERROR CHECK, WRITE, FAILURE and PUNCH programs, the basic element is the "control card format" for each program. Control card listings not enclosed in brackets give the actual command required by the Scope operating system. For use with other computers, an interpretation of the command is given. Comments enclosed in brackets < > are descriptive or explanatory. They merely represent actual cards which must be prepared without brackets or comments. For example, <7-8-9 card> requires a card with a multiple 7-8-9 punch in the first column; it represents an end of logical record.

Following the control card format, notes are provided which explain the preparation or use of the cards and any necessary cautions or restrictions that should be kept in mind. Such matters as computer storage procedures and estimates of storage requirements are also discussed. Finally, where appropriate, sample listings of the control cards and data cards are given.

PREPARING DATA CARDS

Data relating to failures of individual trees are submitted on the "Report of Tree Failure" (*fig. 1*). As the reports are received at the coding office, each is given an accession number and entries are interpreted and coded in accordance with the code manual. The codes are then punched in specified locations on standard 80-column data processing cards. Two cards are required to record relevant data for each failure. A listing of the cards will look like the following example:

```
162721503 10 050 18 2 093 5 01            1 2  87654 63 99 0276 06010 1 1 1 1 0 0 09
1627220                 0 0 0 0              1 WARNER CG                             9
162781803 48 125 09 2 000 1 09            1    87654 63 19 0976 01039 1 2 4 1 0 0 09
1627820                 0 0 0 0              1 INTERP TRAIL                          9
162791001 36 100 02 4 003 2 01 03         9    87654 63 22 1076 01008 1 2 1 2 1 0 00
1627921 CAMPR  200 0 0 0 0 7000        7000  1 XXXXX                                 0
162831572 10 999 01 2 000 3 01 05         9    87654 63 99 0976 01023 1 2 1 1 0 0 09
1628320                 0 0 0 0              1 CAMPSITE 94                           9
162851510 28 999 02 1 010 3 01            9    87654 63 04 1076 01044 1 2 4 1 1 0 00
1628521 FENCE    90 0 0 0 0    90        90  1 30 FT SW OF SANTA CLARA TREE          0
162861505 24 040 20 2 000 4 08 09         1    87654 63 18 0876 01023 1 2 1 1 0 0 09
1628620                 0 0 0 0              1 WAYSIDE CG SITE 18                    9
162871803 64 200 20 2 020 4 01            9    87654 63 99 0976 01042 1 1 1 1 0 0 09
1628720                 0 0 0 0              1 DAVEY BROWN CG                        9
162881824 37 120 17 2 007 5 01            1 6  87654 63 10 1076 20061 1 1 1 1 0 0 09
1628820                 0 0 0 0              1 MARBLE CREEK CG                       9
162891820 18 999 20 2 026 3 01            1    87654 63 20 1076 01019 1 1 1 1 0 0 09
1628920                 0 0 0 0              1 HOEGEE'S TRAIL CAMP                   9
162901301 18 120 13 2 080 5 01            1 2  87654 63 99 0476 06008 2 1 1 1 0 0 09
1629020                 0 0 0 0              1 OLD FOLKS FLAT CG                     9
```

ERROR CHECK PROGRAM

After data have been punched on cards, following the coding manual format, the cards should be checked to insure that no errors have been introduced during the process of coding and punching. The ERROR CHECK program detects illegal code numbers (those not valid for the specific field), lists them, and identifies the detected errors. (The program cannot, for the most part, detect incorrect assignment of valid code numbers.)

By modifying the "standard" error check parameter cards, which are listed in the next section, the user can change the range of illegal code numbers as needed for most data fields. Detection of certain occurrences, such as the illogical combination of failure classes and associated defects, is part of the program and is not easily changed. But the range of illegal species, for example, can easily be restricted or expanded to accept only those species normally reported to a particular agency.

Sample error check test cards are provided for use with the program. Submitting these data to the ERROR CHECK program, either separately or after valid data cards, yields examples of various potential errors. The value of the test cards is to illustrate the manner in which certain errors are indicated by the program, and to verify proper operation of the program should all new data cards be submitted without errors. A listing of the error check test cards is given at the end of this section.

ERROR CHECK Program Control Card Format

< JOB CARD >	
RUN(S)	Compile program
COPYCR(INPUT,CHECKER)	Copy ERROR CHECK cards to file checker
REWIND(CHECKER)	Rewind the file checker
LINK(F=LGO,X)	Load and execute the program
< 7-8-9 CARD >	End of record
< ERROR CHECK PROGRAM DECK >	
< 7-8-9 CARD >	End of record
< A. BLANK CHECK CARDS (2) >	
< B. NUMERIC CHECK CARDS (2) >	
< C. FIELD CHECK CARDS (ANY NUMBER) >	
< 9 CARD (COLUMN 1) >	End of field check cards
< 7-8-9 CARD >	End of record
< ERROR CHECK TEST CARDS - OPTIONAL >	
< DATA CARDS TO BE CHECKED >	
< 6-7-8-9 CARD >	End of job

The listing in the following section shows a "standard" set of the three different types of ERROR CHECK control cards. These "blank," "numeric," and "field" check cards may be used as shown, may be limited to parameters of a specific agency, or may be expanded to accommodate additional species. Normally, an agency would restrict the range of all checks to the limits of agency data. For example, if no site lies above 3900 feet elevation, the illegal parameters on the appropriate field check card (see printout, following location card 12325) would be changed to three blanks followed by ,040-998$.

In the listing, the cards with X's are blank check and numeric check cards. The remainder are field check cards. If different cards are desired, they should be prepared as described here, using the code manual as needed. Note that the code manual requires that the record of each failure begin on one card and end on another, so that each failure is represented by a pair of cards, rather than a single one.

Blank Check Cards

There are two blank check cards, one for each data card of a pair. For each unused column on data cards, a corresponding column on the blank check cards must be blank. For each non-blank data column, enter an X in the corresponding column of the blank check cards.

Numeric Check Cards

There are also two numeric check cards, one for each data card of a pair. For each non-alpha column (blank or numeric) on data cards, the corresponding columns on the numeric check cards must be blank. For all alpha or alpha-plus-numeric fields on data cards, enter X in the corresponding columns of the numeric check cards.

Field Check Cards

This part of the deck may contain any number of field check cards for identified fields. Each data field to be checked requires a location card and one or more parameter cards.

Location card locates a field as follows: Column 1–punch the number of the card containing the specified field (1 or 2 of a two-card data set). Columns 2 and 3–punch first column of field, right justified. Columns 4 and 5–punch last column of field, right justified. (For 1-column fields, columns 4 and 5 will be the same as columns 2 and 3.)

Parameter cards follow each location card, and specify values that are illegal for the field defined in the location card. The number of digits punched for each value should correspond with the code manual and the defined length of the particular field. Parameters begin in column 1 with leading zeros as necessary to match the defined field length. When blanks are illegal, the parameter card starts with the appropriate number of blanks followed by a comma or a dollar sign.

Parameters may be either a single illegal value or a series of individual values and/or ranges. Individual parameters are separated by commas. For ranges, the first and last illegal values are separated by a dash and followed by a comma. The last parameter on a card is followed by an asterisk. The last parameter on the final parameter card for each location card is followed by a dollar sign in place of an asterisk. Additional sets of location cards and parameter cards are used as necessary to define all fields to be checked and the illegal values for such fields.

Listing of Blank Check, Numeric Check, and Field Check Cards

```
XXXXXXXXX XX XXX XX X XXX X XX XX XX X X X XXXXX XX XX XXXX XXXXX X X X X X X XX
XXXXXXX XXXXXXXXXX X X X XXXXXXXXXXXXX XXX XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX X
         X  X   X  X X   X X  X  X  X X X X     X  X  X    X     X X X X X X X
       XXXXXX     X X X X             X   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
10709
   ,000,003,004,008,009,017-020,037-099,108-199,203-209,213-219,222-229,233-269*
272-299,307-349,354-399,404-449,456-459,510-511,515,522,523,532-535,543,549-551*
554,555,558,559,565,569,576,577,580-581,591,595,601,606,607,610,611,619,622,623*
626,627,630,631,642,643,648,649,657,663,667,671,675,682,683,690,691,695,701,707*
717,724,728,729,733,738,743,748,749,761,765,769,773,773779,782,783,788,789*
795-799,819,830-948,950-999$
11112
  ,99$
11416
   $
11819
  ,00,21-98$
12121
 ,0,5-8$
12325
   ,200-998$
12727
 ,0,6-9$
12930
  ,00,17-99$
13233
01,16-99$
13536
01,02,16-99$
13838
 ,0$
14040
1,9$
14242
1-2,9$
14448
    ,00000,01117-01199,01216-01299,01314-01399,01411,01419-01499,01519-01599*
01620-01699,01704-01799,01837-01899,01916-01999,02000-02099,02114-02116,02118*
02123,02125-02130,02141,02147-02199,02201-02210,02212-02299*
02301,02303,02305,02307,02309*
02311,02313,02316-02319,02321-02399,02420-02999*
03001-03100,03102-03201,03203-03306,03308-03406,03408-03510,03512-03612*
03614-03707,03709-03820,03822-03899,04001-04099,04106,04107,04110-04199*
04201-04205,04208,04212-04214,04218-04299,04301-04311,04315-04317,04320-04399*
04401-04422,04425-04499,04501-04599,04601-04620,04622-40099,41001-41099*
41106-41199,41207,41208,41210-41999,42001-42099,42104-42199,42205-42299*
42307-50999,51001-51199,51201-51299,51301-51399,51401-51499,51501-51599*
```

Listing of Blank Check, Numeric Check, and Field Check Cards (continued)

```
51601-51699,51910-51999,52001-52099,52123-52199,52231-52232,52234-52299*
52333-52399*
52436-52499,52528-52599,52620-52999,53001-53099,53101-53999,54001-54004*
54006-54099,54150-54199,54240-54299,54347-54399,54425-54499,54527-54599*
54636-54999,55001-55999,56001-56099,56125-56199,56237-56299,56367-56399*
56430-56499,56520-56999,57801-59999,61001-61509,61511-61999,62001-62999*
63001-63999,66000-69999,70507-70999,72300-73099,73101-73399,73401-73499*
73501-73599,73601-73999,74001-75099,77001-79999,80001-80029,80031-80099*
80102-80199,80201-80299,80301-80399,80407-80499,80501-80599,80601-80699*
80702-99999,03901-03904,03906-03999$

15051
  ,85-99$
15354
  ,00,25-98$
15657
  ,00,13-98$
15859
  ,00-50,76-99$
16162
  ,00,51-99$
16365
   ,253-999$
16767
 ,0,3-9$
16969
 ,0,6-9$
17171
 ,0,9$
17373
 ,0,8,9$
17575
0,2-9$
18080
0-8$
20707
0,2-9$
22020
3-9$
22424
3-9$
22626
 ,3-9$
24042
    ,  0$
28080
0-8$
```

Listing of ERROR CHECK Test Cards

```
000021001 10 300 27 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0000220             0 0 0 1                1 FOREST TYPE ERROR + CLEANUP
000031001 10 300 18 5 005 1 01         1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0000320             0 0 0 1                1 STAND AGE CLASS ERROR TIMBER TYPE    9
000041001 10 300 08 1 005 1            1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0000420             0 0 0 0                1 DEFECT COL BLANK                     9
000051001 10 300 08 1 005 1 05 05      1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0000520             0 0 0 2                1 DEFECT IS REPEATED TWICE             9
000061001 10 300 08 1 005 5 01         4 4   01101 01 20 0769 01010 1 1 1 1 0 0 09
0000620             0 0 0 3                1 CON FACTORS REPEATED TWICE           9
000071001 10 300 08 1 005 5 01           2   01101 01 20 0769 01010 1 1 1 1 0 0 09
0000720             0 0 0 0                1 COL 38 BLANK (CONTRIBUTING FACTOR)   9
000081001 10 300 08 1 005 5 01 11      1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0000820             0 0 0 1                1 DEFECT CONFLICT WITH CLASS OF FAIL   9
000091001 10 300 08 1 005 4 01         3     01101 01 20 0769 01010 1 1 1 1 0 0 09
0000920             0 0 0 2                1 CON. FACTOR CONFLICT CLASS OF FAIL   9
000101001 10 300 08 1 005 1 01         1     05001 01 20 0769 01010 1 1 1 1 0 0 09
0001020             0 0 0 2                1 AGENCY CODE ERROR                    9
000111001 10 300 08 1 005 1 01         1     01101 01 27 0769 01010 1 1 1 1 0 0 09
0001120             0 0 0 3                1 HOUR ERROR                           9
000121001 10 300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 9 1 0 0 09
0001320             0 0 0                  1 LAND OWNERSHIP ERROR                 9
000141001 10 300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 3 1 1 0
0001421 CAR       5 1 1 0 0                1 INJURY--PERSON AFFECTED REC.
000161001 10 300 08 1 005 1 17         1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0001620             0 0 0 0                1 DEFECT ERROR (NO SUCH DEFECT)        9
000171001 1  300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0001720             0 0 0 0                1 DBH ERROR COL 12 BLANK               9
000201001 10 300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 1 2 0 0
0002021 CAR       5 0 0 0 0                1 2 IN COL 75
000221888 10 926 82 7 005 6 18 05 02 9 2 3 01101 01 20 1369 51010 1 1 1 1 2 0 0
0002222 CAR       5 0 0 0 0                1 2 IN COL 75 AND 2/7 + MULTIPLES      9
000231      36 250 06 4 055 2 16       1 2   01517 04 99 0174 01031 2 1 1 1 0 0 09
0002320             0 0 0 0                1 COLUMN  7-9 (NO SPECIES)             9
000321 88      888 21 0 978 8 20 03 03 2 1          66 09 0077 09444 322 2 2 3 3 39
0003220             0 0 0 0                  MULTIPLE ERROR TESTER                9
000351001 10 300 08 1 005 2 01 051     1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0003520             0 0 0 0                1 COL 34 SHOULD BE BLANK               9
000371701 10 300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0003820             0 0 0 0                1 CLASS OF FAIL ERROR (NO SUCH CLASS)  9
000391001 10 300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 2 1 3 3
0003921           5 2 3 2 0                1 CHECK ON MULTIPLE INJ + FAT
000401001 10 300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 1 0 0 0
0004020             0 0 0 0                1 NO 9 IN COL 80 ON CARDS 1 OR 2
000411001 10 300 08 1 005 5 04 01      1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0004120             0 0 0 0                1 DEFECTS OUT OF ORDER                 9
000431001 10 300 08 1 005 1 01         1     01101 01 20 0769 01010 1 1 1 1 0 0 09
0004310             0 0 0 0                1 2 CARD HAS 1 IN COL. 6               9
```

WRITE PROGRAM

Using the cards that have been checked for errors and corrected, the WRITE program creates data tapes to be used with the FAILURE programs. The WRITE program also edits and deletes data, and makes additions to existing data on tape.

WRITE Program Control Card Format

< JOB CARD >	
RUN(S)	Compile Program
COPYCR(INPUT,TAPE3)	Copy the data deck to the disk file TAPE3
REWIND(TAPE3)	Rewind the file TAPE3
REQUEST(TAPE2)27604	Mount the current data tape as file TAPE2
LINK(F=LGO,X)	Load and execute the program
UNLOAD(TAPE2)	Release the tape drive
REQUEST(NEW,W)27605	Mount the new data tape
REWIND(TAPE1)	TAPE1 is a disk file containing the new data
COPY(TAPE1,NEW)	Copy TAPE1 to the tape file, NEW
UNLOAD(NEW)	Release the tape drive
REQUEST(BACK,W)10407	Mount another tape and copy the
REWIND(TAPE1)	contents of TAPE1 to it for a
COPY(TAPE1,BACK)	back-up of the reel 27605
< 7-8-9 CARD >	End of record
< WRITE PROGRAM DECK >	
< 7-8-9 CARD >	End of record
LISTA < OR LIST >	See Notes
< 1LINE (OPTIONAL) >	
EDIT < OR DATA >	See Notes
< NEW DATA CARDS >	
END	End of data cards
< 6-7-8-9 CARD >	End of job

Notes on WRITE Program

For WRITE, the new data cards, or the cards to edit existing data, or both together, should be put in sequential order, with card 1 of each pair immediately preceding card 2, before they are added to the data tape.

The control card format as shown provides for a method—not required, but convenient—whereby three data tapes, one of which is a backup, are used. During the process of adding or editing data, records from the current tape (27604) are copied to the new tape (27605), except that those records to be edited are replaced by the input data cards. When all old data are copied or edited, any new data sets remaining in the card deck are also added to the new tape (27605). Subsequently, the same file is written to the backup tape (10407).

In this process, 27605 has become the "new" or current data tape. In the next revision, 27605 will be called first and the edited data will be written back onto 27604. Thus, the two data tapes are alternately assigned as the new tape. Backup 10407 is always a copy of the most recent of the two data tapes. (The tape numbers actually assigned to tapes will vary depending on the applicable tape numbering system.)

LISTA

Precedes EDIT or DATA card. LISTA provides a listing of the entire new tape.

LIST

Precedes EDIT or DATA card. May be used in place of LISTA. LIST provides a listing only from first new or first edited data item to the end of all data.

1LINE

If one-line printed output without comments and other non-numeric information is also desired, insert 1LINE after LISTA or LIST and before EDIT card. LISTA or LIST may be omitted to suppress the two-card image listing.

EDIT

Must always be used when one or more data records in the old data file are to be replaced with new data, or new data are being added. The new data cards follow the EDIT card and are followed by an END card. Revised data cards used with EDIT delete the old records and replace them with the new data bearing the same accession numbers.

Special Note: To delete data for a pair of cards without an immediate replacement, prepare only card 1 of the pair, with an asterisk (*) in column 6 after the accession number. Place the card in numerical sequence with the other data cards to be edited or added to the data tape.

DATA

Must be used to build a new data tape the first time data for a user's agency or specific unit are recorded on tape. It is used in place of EDIT. Data are written from cards to fresh tape. LIST or LISTA card must precede DATA card.

END

Must be the next-to-last card in the deck immediately after data cards and is followed only by an "end of job" card.

FAILURE PROGRAM

The FAILURE program provides for retrieval from the data tape of selected classes or groups of data as required. The selected data are summarized and presented in one of seven tables according to the type of analysis and format desired.

The seven FAILURE tables are produced by four programs. (These originally formed a single program, but turn-around time was excessive. Rather than redesign the program to use overlays, we separated the table functions by making four copies of the program. We removed from each copy all but the selected table summaries, thus obtaining four smaller programs which would use less central memory for any given problem.) Separate programs (FAIL3, FAIL6, and FAIL7) produce each of the three largest tables. The remaining program (FAIL15) produces tables 1, 2, 4, and 5.

FAILURE Program Control Card Format

< JOB CARD >	
REQUEST(FAIL)40972	Mount tape containing appropriate FAIL program
REQUEST(TAPE1)27605	Mount current data tape
LINK(F=FAIL,X)	Load and execute the FAIL program
< 7-8-9 CARD >	End of record
< TABLES CARD >	See notes
< LEVEL SELECTOR CARDS >	See notes
< BLANK CARD >	End of level selector cards
< 6-7-8-9 CARD >	End of job

Notes on FAILURE Program

1. TABLES card shows the word TABLES in column 1-6 and the number of the table desired (1-7) in column 8.

2. For all tables, level selector card sets for species must be last in series if species are to be individually identified and analyzed. Each level must include all data required from subsequent levels (with higher level numbers). (See explanation of level selector cards below.)

Table 1 always requires a level selector card set for species (even when data for all species are desired). Species card sets must be last in series.

3. Table 6 will contain fewer data than other tables because on some failure reports, hour or month information is missing. Table 6 does not include "hour=99" or "month=99" (unknown) data (see coding manual).

FAILURE Tables

This summary of the tables indicates their content: they are listed here in order of utility. (The terms 1-way, 2-way, and 3-way refer to the number of interrelations analyzed in the table.)

Table 7: 1-way, three parts
Failures, accidents, and losses by (A) class of failure, (B) defects, and (C) environmental factors.[4] (No direct interrelations are shown between A, B, and C.)

Table 1: 1-way
Frequency of failures by species code number.

Table 5: 2-way, two parts
Frequency of failures by (A) class of failure by defect, and (B) class of failure by environmental factor.

Table 4: 3-way, one table for each class of failure
Frequency of failures by class of failure, by defect by environmental factor.

Table 6: 3-way, one group of tables for each factor, one table for each class of failure
Frequency of failures by selected environmental factor (wind, unknown/none, other), by class of failure, by month by hour of the day.

Table 2: 3-way, one table for each defect
Frequency of failures by defect, by environmental factor by class of failure.

Table 3: 3-way, two parts, one table for each defect, and one table for each factor
Frequency of failures (A) by defect, by species by class of failure; and (B) by environmental factor, by species by class of failure.

Examples of the tables given in a later section illustrate their general form. (Because of their length, it is not feasible to show complete examples of all formats.)

Restriction of the data to produce the desired tables is accomplished in the programs by means of level selector cards. The preparation of these cards, according to the coding manual, is explained below. Temporary storage file requirements of the various levels must be provided for in advance; instructions for this are also given in a later section.

Use of Level Selector Cards in FAILURE Program

To obtain the desired analysis, once the TABLES card has specified the table format, the level selector card must be entered to specify the part of the data to be included. There are 28 selector field names which can be used with FAILURE. The list of names includes an explanation of the name and the location of the entry for that name on the data card (either card 1 or card 2 of the two-card set for each failure record). Note: The list includes four names to cover levels of U.S. Forest Service administration—AGENCY, REGION, FOREST, and DISTRICT. These can be used to cover similar levels of administration in other organizations. State or Federal parks are given code numbers under FOREST (see code manual).

[4] The terms "environmental factor" and "contributing factor" are used interchangeably in the programs.

28 Selector Field Names for FAILURE Program

See coding manual for related code numbers. Far right column gives location of information on data card.

Selector field name	Meaning	Card number and column
NUMBER	Accession or incident number (e.g., 5R12345)	1/1-5 (2/1-5)
SPECIE	Tree species	1/7-9
DBH	Diameter at 4.5 feet	1/11-12
AGE	Age of tree	1/11-12
TIMBER	Forest type	1/18-19
STAND	Stand age class	1/21
ELEV	Elevation divided by 100	1/23-25
DEFECT	Causal defect	1/29-30
FACTOR	Causal environmental factor	1/38
AGENCY	Agency designation, 1st level	1/44-45
REGION	Agency designation, 2nd level	1/46
FOREST	Forest or park designation, 3rd level	1/47-48
DISTRT	District designation, 4th level	1/50-51
HOUR	Time of failure	1/53-54
MONTH	Month of failure	1/56-57
YEAR	Year of failure	1/58-59
STATE	State in which failure occurred	1/61-62
COUNTY	County in which failure occurred	1/63-65
SEASON	Whether in season for public use	1/67
OWNER	Land ownership	1/69
SITE	Site category	1/71
TARGET	Property or person affected	1/73
IFPROP	Property accident	(1/75) 2/7
INJURY	Number of injuries	(1/77) 2/20
MEDATT	Number requiring medical attention	2/22
FATAL	Number of fatalities	(1/79) 2/24
CLAIM	Failure category—normal, catastrophe, or urban	2/26
CLEAN	Cleanup required	(1/80) 2/80

Preparing Selector Cards

The selector names chosen for a specific table must be numbered in sequence; these are the *levels* of the analysis. (The number of levels is limited as explained below.) A series of level selector card sets is prepared, with reference to the code manual, in the manner described here.

Card 1 of a set

Card 1 defines the data field to be searched. In column 2 of the card, the level number (the sequence number for the field names) is entered. Repetitions of a particular selector field name (to cover more than one range in the field) retain the same level number. (In the example of selector card sets see level "3 FOREST" and level "4 YEAR.")

In columns 4 through 9, the selector field name is entered in the required form shown in the list.

In columns 11 through 13, a "total" number is entered (right justified), that tells how many separate code numbers are to be searched in that repetition of the level. (The actual code numbers are given on card 2.) However, if the code numbers embrace a continuous series with no omissions, no entry is made in columns 11 to 13.

The title of the field starts in column 15 and may be continued through column 44 at most, except that for table 3 the title must terminate by column 32. Any desired informative title may be used.

Card 2 and following of a set

The second card contains the codes for the desired items for that repetition within the designated selector field. The card begins in column 1, with 5-digit fields for each code number. Numbers are entered in sequence, with zeros preceding each as necessary to make each number 5 digits long. For example, if the desired code numbers are 3,7, and 9, they would be written 000030000700009. If more than 16 individual code numbers are needed for SPECIE, they are entered continuously in fields of five on subsequent cards. If the code numbers form an unbroken series, only the first and final numbers are written. For example, 1 through 9 is written 0000100009. (Note, however, that if card 1 shows a 2 in column 13, the program would select only code 1 and code 9. ignoring 2 through 8.)

Coding of certain items on selector card sets may differ from that on data card sets. In the coding manual and on data cards, code numbers vary in length from one to five digits depending on the items. On data cards, moreover, most code fields are separated by blanks. Exceptions to this rule are certain groups of field names: the accession number, card number, and tree species which occur in an unbroken series; the month and year; the state and county; and the agency, region, and forest. In the last group, only the first two digits of the five-digit combination refer to the selector AGENCY. The third digit is the code for REGION, and the last two positions define the selector FOREST. In the selector card sets, a separate level is required for each selector name in a group. For example, on data cards, Los Padres Forest in Region 5 of the U.S. Forest Service is coded 01507. On the selector card set, however, to retrieve specific information for the Los Padres, the selector AGENCY is written 00001 on card 2, REGION is 00005, and FOREST is 00007. These would be levels 1,2, and 3.

In FAILURE, a maximum of 10 levels (10 different selector names) may be used in one run. A maximum of 100 selector title cards (100 levels and repetitions combined), may be used in each execution. For each repetition of the selector name SPECIE there is a limit of 200 individual specifications within the repetition. For each repetition of any other selector, there is a limit of 10 individual specifications within the repetition. For example, within FOREST only 10 individual forests can be specified for each repetition; for DBH only 10 individual inch measurements can be specified for each DBH repetition. A continuous range is not subject to this restriction, however.

For discontinuous code numbers, then, with a maximum of 16 code numbers per card, there can be 12 ½ cards for a SPECIE repetition. There can only be one card, with at most 10 specifications, within any single repetition of a selector other than SPECIE.

The number of tables that will be produced is equal to the product of the repetitions per level. The following example would create 1 X 1 X 2 X 4 X 1 or 8 tables.

Example of Selector Card Sets

```
 < 7-8-9 CARD >
TABLES 7
 1 AGENCY    1 CALIFORNIA STATE PARKS + REC
00052
 2 REGION    1 DISTRICT 4
00004
 3 FOREST      ALL PARKS IN DISTRICT
0000100035
 3 FOREST    1 BLANK STATE PARK
00001
 4 YEAR        ALL YEARS
0003800076
 4 YEAR      1 1976
00076
 4 YEAR      1 1977
00077
 4 YEAR      1 1978
00078
 5 SPECIE   41 MINOR HARDWOODS
005020050400508005090051100513005140051500516005170051800519005200052100522005 23
0052400525005260052700528005290053000531005320053300534005350053600537005380053 9
005400054100542005430054400545005460054700548
 < BLANK CARD >
 < 6-7-8-9 CARD >
```

Computer Storage Requirements

The FAILURE program requires a maximum of 10 temporary files on a magnetic disk, or drum. The files, called scratch files, are used by the program to store the subset of data required at each level of the summary, according to the table selected by the user, and the selector field names chosen. The first scratch file contains the data selected at the first level, the second scratch file contains the data selected for the second level, and so on. Thus, the number of files to be used is predictable. The size of each file is not so easily known, however. This depends on the degree of restriction represented by the user's choice of table format, selector fields, and selector codes, to fit his particular problem. The first scratch file may be small, or may be nearly as large as the data set itself. The other scratch files will grade downward at some rate peculiar to the problem. If the user's computer system requires a special request for scratch storage space, he will need to make some trials with the programs before he can estimate exactly what is necessary.

As many as nine levels may be written to scratch files—one less than the number of levels needed for the job. TAPE1 is the file name for the data tape itself; the scratch file names are TAPE2 through TAPE10. (TAPE11 is also used, but it is a storage file for a table of species selectors. See coding manual.)

Central memory or core requirements are as follows:

File	*Name*	*Core*
1	FAIL7	60000
2	FAIL15	64000
3	FAIL3	137000
4	FAIL6	63000

Examples of Failure Analysis Tables

General note: The sample data shown in the tables given here are incomplete, and are drawn from only one state. Also, for convenience, parts of long tables or wide-page tables have been omitted, as indicated by the jagged lines.

Table 7

To produce this example of the output for Table 7, the following steps have been taken:

1. A data tape has been established in the computer through proper coding and punching of data cards and use of the ERROR CHECK and WRITE programs as described.
2. The proper control card format for the FAILURE program, for table 7, has been followed.
3. Three levels of selector names have been chosen: AGENCY, REGION, and CLAIM. Selector card sets have been properly prepared, using the coding manual for the information desired at each level, and these have been entered in the program, preceded by the TABLES 7 card, and followed by a blank card. The result is a table 7 format analysis of all noncatastrophe failures which have been recorded for the specified regions of the selected agencies.

Other Tables

These tables have been produced in a manner similar to that used for table 7. Selector card sets have been prepared for the information desired at each level.

```
SELECTOR INDEXES AND TITLES
===========================

1. SELECTED AGENCIES

    2. SPECIFIED REGIONS

       3. NONCATASTROPHE
```

TABLE 7A -- TOTAL NUMBER OF ACCIDENT FAILURES

BY CLASS OF FAILURE FOR ALL SPECIES (001-999)

CLASS OF FAILURE	PROP DAMAGE	INJURY	FATALITY	ACCIDENT FAILURES	TOTAL FAILURES	PERCENT FAILURES	PROP LOSS	MED ATTN REQUIRED
LIMB	76	7	1	78	311	.25080	20750	4
UPPER BOLE	91	3	3	94	653	.14395	37070	2
LOWER BOLE	104	5	5	105	601	.17471	100696	5
BUTT	95	13	3	100	619	.16155	69078	11
ROOT	197	14	11	201	1831	.10978	133903	14
* TOTAL *	563	42	23	578	4015	.14396	361497	36

TABLE 78 -- TOTAL NUMBER OF ACCIDENT FAILURES

BY DEFECTS/FAULTS FOR ALL SPECIES (001-999)

DEFECTS/ FAULTS	PROP DAMAGE	INJURY	FATALITY	ACCIDENT FAILURES	TOTAL FAILURES	PERCENT FAILURES	PROP LOSS	MED ATTN REQUIRED
ROT	271	19	4	274	1817	.15080	177318	15
SWEEP	1	0	0	1	15	.06667	100	0
TREE DEAD	59	10	5	62	385	.16104	29000	9
FIRE WOUND	20	2	4	20	100	.20000	25990	2
LEANING	57	9	5	60	394	.15228	31833	9
LIGHTNING	6	2	1	7	60	.11667	2200	1
MECH WOUND	11	0	0	11	112	.09821	710	0
CRACK/SPLIT	14	1	1	15	100	.15000	6985	1
FORK TOP	24	2	2	25	87	.28736	16535	1
TWIN BOLE	9	3	3	10	50	.20000	11730	3
DEAD TOP/BR	23	3	0	23	133	.17293	2717	0
WIDOW-MAKER	2	0	0	2	23	.08696	1722	0
CANKER,RUST	5	0	0	5	22	.22727	5915	0
CANKER,MIST	9	0	0	9	15	.60000	3585	0
OTHER	8	1	1	8	53	.15094	20437	0
UNKNOWN/NONE	165	8	7	170	1279	.13292	107217	8

TABLE 7C -- TOTAL NUMBER OF ACCIDENT FAILURES

BY CONTRIBUTING FACTORS FOR ALL SPECIES (001-999)

CONTRIB FACTORS	PROP DAMAGE	INJURY	FATALITY	ACCIDENT FAILURES	TOTAL FAILURES	PERCENT FAILURES	PROP LOSS	MED ATTN REQUIRED
WIND	403	25	19	413	3015	.13698	288813	21
SNOW	109	1	0	109	731	.14911	56547	1
EROSION	7	0	1	7	54	.12963	3580	0
SOIL SATUR	57	3	5	57	383	.14883	54178	3
STREAM EROS	13	5	1	13	147	.08844	8775	5
SHALLOW ROOT	38	0	0	38	316	.12025	24805	0
TREE X TREE	3	2	2	3	70	.04286	2640	2
OTHER	11	1	0	11	94	.11702	2545	0
UNKNOWN/NONE	86	11	2	91	572	.15909	26731	9

TABLE 1

TOTAL NUMBER OF TREE FAILURES
BY INDIVIDUAL SPECIES

SPECIES	TOTAL
1	1194
2	9
5	859
824	7
826	6
ALL SPECIES	7830

TABLE 5A -- TOTAL NUMBER OF TREE FAILURES BY DEFECT/FAULT AND CONTRIBUTING FACTOR FOR ALL SPECIES

CLASS OF FAILURE	TOTAL IN GROUP	CLEAN UP ONLY	ROT	SWEEP	SNAG	FIRE	LEAN	DEAD TOP	WIDOW-MAKER	CANKER, RUST	CANKER, MIST	OTH.	UNK. OR NONE
UP BOLE	857	746	185	5	62	13	72	32	6	5	12	6	451
LOW BOLE	1089	977	296	4	88	24	84	0	0	1	8	8	652
ALL BOLE*	1946	1723	481	9	150	37	156	32	6	6	20	14	1103
BUTT	1319	1194	995	5	81	41	728	0	1	1	0	16	167
LIMB	2027	1866	223	0	9	5	1	68	17	1	9	20	1651
ROOT	2538	2275	518	9	100	45	324	0	1	0	0	19	1734
* TOTAL *	7830	7058	2217	23	340	128	1209	100	25	8	29	69	4655

CLASS OF FAILURE	CONTRIBUTING FACTORS: WIND	SNOW	EROSION	SOIL SAT.	STR. EROSION	SHALLOW ROOT	TREE STK. TREE	OTHER	UNK. OR NONE
UP BOLE	342	440	0	1	0	0	32	12	106
LOW BOLE	374	615	0	0	0	0	24	11	132
ALL BOLE*	716	1055	0	1	0	0	56	23	238
BUTT	403	745	0	0	0	0	34	10	176
LIMB	268	1613	0	0	0	0	6	14	174
ROOT	1083	810	73	898	314	240	107	37	124
* TOTAL *	2470	4223	73	899	314	240	203	84	712

TABLE 5B -- PERCENTAGE OF TREE FAILURES BY DEFECT/FAULT AND CONTRIBUTING FACTOR FOR ALL SPECIES

CLASS OF FAILURE	TOTAL IN GROUP	CLEAN UP ONLY	ROT	SWEEP	SNAG	FIRE	LEAN	WID-OW-MAKER	CAN-KER, RUST	CAN-KER, MIST	OTH.	UNK. OR NONE
UP BOLE	1.00	.87	.22	.01	.07	.02	.08	.01	.01	.01	.01	.53
LOW BOLE	1.00	.90	.27	.00	.08	.02	.08	0.	.00	.01	.01	.60
ALL BOLE*	1.00	.89	.25	.00	.08	.02	.08	.00	.00	.01	.01	.57
BUTT	1.00	.91	.75	.00	.06	.03	.55	.00	.00	0.	.01	.13
LIMB	1.00	.92	.11	0.	.00	.00	.00	.01	.00	.00	.01	.81
ROOT	1.00	.90	.20	.00	.04	.02	.13	.00	0.	0.	.01	.68
* TOTAL *	1.00	.90	.28	.00	.04	.02	.15	.00	.00	.00	.01	.59

TABLE 4 -- FREQUENCY OF ASSOCIATION OF DEFECTS/FAULTS WITH CONTRIBUTING FACTORS FOR ALL SPECIES

CLASS OF FAILURE -- UP BOLE

DEFECT/FAULT	WIND	SNOW	EROSION	OTHER	UNK/NONE
ROT	126	32	0	0	48
SWEEP	4	0	0	0	1
TREE DEAD	31	2	0	0	30
FIRE WOUND	11	8	0	0	2
LEANING	28	25	0	5	19
LIGHTNING	2	0	0	0	9

TABLE 4 -- FREQUENCY OF ASSOCIATION OF DEFECTS/FAULTS WITH CONTRIBUTING FACTORS FOR ALL SPECIES

CLASS OF FAILURE -- * TOTAL *

DEFECT/FAULT	WIND	SNOW	EROSION	OTHER	UNK/NONE
ROT	1001	794	16	23	418
SWEEP	16	0	1	0	4
TREE DEAD	170	19	3	6	134
FIRE WOUND	75	18	3	2	43
LEANING	338	702	25	15	117
LIGHTNING	5	1	0	0	11

TABLE 6A -- TOTAL NUMBER OF TREE FAILURES BY MONTH AND HOUR DUE TO WIND FOR ALL SPECIES

CLASS OF FAILURE -- UPPER BOLE

MONTH	1	2	3	4	5	6	7	8	9	20	21	22	23	24
JAN	4 .12	2 .06	2 .06	4 .12	4 .12	1 .03	2 .06	1 .03	2 .06	1 .03	0 0.	0 0.	3 .09	2 .06
FEB	2 .12	0 0.	0 0.	4 .24	0 0.	0 0.	1 .06	0 0.	0 0.	1 .06	0 0.	3 .18	1 .06	1 .06
MAR	0 0.	0 0.	1 .10	1 .10	0 0.	0 0.	0 0.	0 0.	0 0.	1 .10	1 .10	1 .10	0 0.	0 0.
APR	0 0.	0 0.	0 0.	1 .20	0 0.	0 0.	1 .20	0 0.	0 0.	0 .	0 0.	0 0.	0 0.	0 0.
DEC	0 0.	14 .22	2 .03	24 .38	3 .05	0 0.	0 0.	0 0.	4 .06	5 .08	0 0.	1 .02	2 .03	0 0.
YEAR	8 .04	20 .10	6 .03	34 .16	7 .03	4 .02	6 .03	4 .02	8 .04	8 .04	4 .02	6 .03	11 .05	15 .07

Tables 6B and 6C provide data for "unknown/none" or "other" as environmental factor.

TABLE 2A -- FREQUENCY OF ASSOCIATION OF DEFECTS/FAULTS WITH CONTRIBUTING FACTORS BY CLASS OF FAILURE
TOTAL TREE FAILURES FOR ALL SPECIES

FACTORS		TOTAL	ROOT	UPPER BOLE	LIMB
ROT	- WIND	1001	311	126	117
ROT	- SNOW	794	54	32	41
ROT	- EROSION	16	16	0	0
ROT	- SOIL SATURTN	213	213	0	0

FACTORS		TOTAL	ROOT	UPPER BOLE	LIMB
GRAND	- TOTAL	11395	4027	1111	2162

Table 2B provides data corresponding to 2A, in percentages; see table 5B.

TABLE 3A -- TOTAL NUMBER OF TREE FAILURES
ASSOCIATED WITH ROT

SPECIES	UPPER BOLE	LOWER BOLE	SUBTOTAL	LIMB	TOTAL
11	3 .05000	16 .26667	19 .31667	0 0.	60
12	6 .11765	13 .25490	19 .37255	2 .03922	51
15	3 .04839	18 .29032	21 .33871	1 .01613	62
24	0 0.	11 .42308	11 .42308	1 .03846	26
25	23 .23469	13 .13265	36 .36735	6 .06122	98
5 CALIF. PINES	35 .11785	71 .23906	106 .35690	10 .03367	297

TABLE 3B -- TOTAL NUMBER OF TREE FAILURES

ASSOCIATED WITH WIND

SPECIES	UPPER BOLE	LOWER BOLE	SUBTOTAL	LIMB	TOTAL
11	41 .27152	35 .23179	76 .50331	4 .02649	151
12	19 .18812	21 .20792	40 .39604	9 .08911	101
15	15 .10274	33 .22603	48 .32877	1 .00685	146
24	3 .08108	15 .40541	18 .48649	1 .02703	37
25	39 .15918	21 .08571	60 .24490	13 .05306	245
5 CALIF. PINES	117 .17206	125 .18382	242 .35588	28 .04118	680

PUNCH PROGRAM

The PUNCH program is designed to create quasi-original data cards from a data tape, and also to provide subsets of data as listings or tapes. The program allows selection of any desired data card sets from the data tape. Selector names for any data fields can be specified and the range within fields can be restricted as needed. Using this procedure, one may, for example, request all data for a given species, for a limited diameter range, for only certain types of sites within one district of a forest of the U.S. Forest Service in the state of Montana. A single run will produce either or both of two forms of data card listing and/or quasi-original punched cards that may be treated as originals for subsequent computer analyses. One form of listing (1LINE) provides all the numeric data available in a single line for each numbered incident. The other listing shows both alpha and numeric data as they would appear on each data card pair, whether or not punched cards are actually produced as desired output. The PUNCH program can also be used to create a new tape containing a subset of data from an existing tape. This new tape can thereafter be treated as an original data tape and subjected to FAILURE analyses or even to subsequent PUNCH programs.

The control card format for PUNCH, given in the next section, includes the complete program listing. Because PUNCH is a short program, it has been provided here rather than on the tape available on request. Therefore, each time the program is used, the program cards shown must be submitted to the computer.

PUNCH Program (Complete Listing)

```
 < JOB CARD >
RUN(S)                              (COMPILE PROGRAM)
REQUEST(TAPE1)27604                 (MOUNT CURRENT DATA TAPE)
LINK(F=LGO,X)                       (LOAD AND EXECUTE THE PROGRAM)
REWIND(PUNCH)                       (REWIND PUNCH FILE)
COPYSBF(PUNCH,OUTPUT)               (PRINT AND DELETE PUNCH FILE)
 < 7-8-9 CARD >                     (END OF RECORD)
      PROGRAM DATAOUT(PUNCH=7001,OUTPUT=7001,TAPE1=3001,INPUT)
      INTEGER SPECIE, DBH, AGE, TIMBER, STAND, ELEV, CLASS, DEFECT(3),
     $        FACTOR(3), AGENCY, REGION, FOREST, DISTRT, HOUR, YEAR,
     $        STATE, COUNTY, SEASON, OWNER, SITE, TARGET, FATAL, CLAIM,
     $        CDOLLAR, SETTLE, SDOLLAR, TREES, CLEAN
      COMMON BUFFER, IDATA
      INTEGER PUNCH, IDATA(45), BUFFER(5000)
      LOGICAL READB
      EQUIVALENCE
     $ (IDATA( 1),NUMBER ), (IDATA( 2),SPECIE ), (IDATA( 3),DBH     ),
     $ (IDATA( 4),AGE    ), (IDATA( 5),TIMBER ), (IDATA( 6),STAND   ),
     $ (IDATA( 7),ELEV   ), (IDATA( 8),CLASS  ), (IDATA( 9),DEFECT  ),
     $ (IDATA(12),FACTOR ), (IDATA(15),AGENCY ), (IDATA(16),REGION  ),
     $ (IDATA(17),FOREST ), (IDATA(18),DISTRT ), (IDATA(19),HOUR    ),
     $ (IDATA(20),MONTH  ), (IDATA(21),YEAR   ), (IDATA(22),STATE   ),
     $ (IDATA(23),COUNTY ), (IDATA(24),SEASON ), (IDATA(25),OWNER   ),
     $ (IDATA(26),SITE   ), (IDATA(27),TARGET ), (IDATA(28),IFPROP  ),
     $ (IDATA(29),LOSS   ), (IDATA(30),INJURY ), (IDATA(31),MEDATT  ),
     $ (IDATA(32),FATAL  ), (IDATA(33),CLAIM  ), (IDATA(34),CDOLLAR),
     $ (IDATA(35),SETTLE ), (IDATA(36),SDOLLAR), (IDATA(37),TREES   ),
     $ (IDATA(38),CLEAN  )
      CALL FET(5LTAPE1,2000 0000 0000 0000 0000B,8*64)
      MT=1
      ASSIGN 1000 TO NOPUNCH
      ASSIGN 2000 TO PUNCH
      READ 10,LIST
   10 FORMAT(A5)
      IF(LIST.NE.5H1LINE) GO TO 1000
      KOUNT = 0
      PRINT 9000
      PRINT 9001
```

PUNCH Program (Complete Listing) (continued)

```
 1000 READ(1) IDATA
      DO 50 I=1,38
      IDATA(I)=-IDATA(I)
   50 CONTINUE
      IF(IDATA(1).EQ.5REND  ) STOP
      IF(IDATA(1).EQ.5RDATA ) GO TO 1000

<    INSERT 'IF' STATEMENT SELECTOR CARDS HERE BEFORE RUN.     >

 2000 IF(LIST.NE.5H1LINE) GO TO 2025
      IF ( KOUNT .LT. 50 ) GO TO 2025
      PRINT 9002
      PRINT 9001
      KOUNT = 0
 2025 CONTINUE
      DO 2026 I=1, 38
      IF ( IDATA(I) .EQ. 0 ) IDATA(I) = 0
 2026 CONTINUE
      IF(LIST.EQ.5H1LINE)PRINT 9003,(IDATA(I),I=1,38)
      PUNCH 9004,(IDATA(I),I=1,27),IDATA(1),IDATA(28),IDATA(39),
     1  (IDATA(I),I=29,37),(IDATA(I),I=40,45),IDATA(38)
      KOUNT = KOUNT + 1
      GO TO 1000
 9000 FORMAT(1H1,41X,31H*** LISTING OF PUNCHED DATA *** // )
 9001 FORMAT (  1X,  111(1H=) / 1X,111H  ID   SP DBH AGE TT S ELE F DEFE
     $CT/F CONTR AG R FO DI HR MO YR ST CO S O S P D LOSS I M F C CLAIM
     $S SAMT NUM C / 1X, 110(1H=) // )
 9002 FORMAT(1H1,35X,43H*** LISTING OF PUNCHED DATA (CONTINUED) ***//)
 9003 FORMAT(1X,R5,I5,I3,I4,I3,T2,I4,I2,3I3,3I2,I3,I2,7I3,5I2,I5,4I2,I6,
     $       I2,I5,I4,I2)
 9004 FORMAT(R5,1H1,I3,I3,I4,I3,I2,I4,I2,3I3,3I2,I3,I1,I2,3I3,I2,2I3,4I2
     $  /R5,1H2,I1,1X,A5,I5,4I2,I5,I1,I6,I4,1X,5A6,A5,1X,I1)
      END
 < 7-8-9 CARD >               (END OF RECORD)
1LINE
 < 6-7-8-9 CARD >             (END OF JOB)
```

Specifying Form of Output

The control card format as shown will produce a two-card image listing and a 1LINE (numeric data) listing as well as punched card output. To obtain alternative combinations of output, cards may be added or omitted as follows:

To suppress two-card image listing, remove:
REWIND(PUNCH)
COPYSBF(PUNCH,OUTPUT)

To suppress 1LINE listing, remove after END card:
7-8-9
1LINE

To suppress punched card output, insert:
REWIND(PUNCH)
WRITEF(PUNCH)
after
REWIND(PUNCH)
and
COPYSBF (PUNCH,OUTPUT)
or in place of these two cards if the two-card image listing is not needed.

Preparing Statement Cards to Specify Selector Fields and to Restrict Data

Statement cards are inserted in the PUNCH program at the point shown in the program listing. Any field or combination of 38 named selector fields may be searched. Restriction of data within a field is made by conventional FORTRAN IF statements. Code numbers are specified which are either equal to, not equal to, less than, or greater than the numbers representing the desired characteristics selected for punching. Relationships between fields may be additive or restrictive.

As many statement cards specifying selectors may be used as needed. When selector fields are restrictive, there should be only one IF statement for each selector field. The IF statements must be capable of only two possible interpretations—true or false. The computer must "know" whether to "punch" or not. Examples of suitable statements are given in a later section.

Statement cards begin in column 7 with IF and (, or open parenthesis. Card must end, or be continued to another card, with column 72. The first card remains blank in column 6. When a statement continues on a following card, the following card(s) must have a character other than a zero punched in column 6. The dollar sign ($) has been used in this program for continuation. Spaces have no significance in these statements. The last statement card must end with a close parenthesis, followed by either GO TO NOPUNCH or GO TO PUNCH. If it ends with GO TO PUNCH it must be followed by a separate GO TO NOPUNCH card. Unlike the IF statement cards, the separate GO TO NOPUNCH card is punched starting in column seven. If GO TO NOPUNCH concludes the last of the statement cards, omit separate GO TO NOPUNCH card.

Note: When DEFECT or FACTOR is a chosen selector, the order of selection desired must be specified (see examples of IF statements). This is because the coding manual provides that up to three of each of these items can be punched, in separate locations. If all occurrences of any one defect or factor are to be selected, the defect or factor must be searched for in all three locations. Exceptions are the defects "rot" and "unknown," and the factors "wind" and "unknown," which are always in the first location of the appropriate field (see coding manual).

When NUMBER is a selector, the desired five-digit accession numbers must each be preceded by 5R (e.g., 5R12345).

Blanks and zeros should be assumed equivalent in all columns which are used for data.

Redundancy—to improve accuracy in coding, columns 75, 77, 79, and 80 on card 1 are duplicated in columns 7, 20, 24, and 80 on card 2.

38 Selector Field Names for PUNCH Program

See coding manual for related code numbers. Next-to-last column gives location of information on data cards. Last column gives abbreviated forms that will appear as headings on 1LINE output.

Selector field name	Meaning	Card number and column	1LINE Title
NUMBER	Accession or incident number (e.g., 5R12345)	1/1-5 (2/1-5)	ID
SPECIE	Tree species	1/7-9	SP
DBH	Diameter at 4.5 feet	1/11-12	DBH
AGE	Age of tree	1/14-16	AGE
TIMBER	Forest type	1/18-19	TT
STAND	Stand age class	1/21	S
ELEV	Elevation divided by 100	1/23-25	ELE
CLASS	Class of failure	1/27	F
DEFECT(1)	Causal defect	1/29-30	DEFECT/F
DEFECT(2)	Causal defect	1/32-33	DEFECT/F
DEFECT(3)	Causal defect	1/35-36	DEFECT/F
FACTOR(1)	Causal environmental factor	1/38	CONTR
FACTOR(2)	Causal environmental factor	1/40	CONTR
FACTOR(3)	Causal environmental factor	1/42	CONTR
AGENCY	1st level agency designation	1/44-45	AG

38 Selector Field Names for PUNCH Program (continued)

REGION	2nd level agency designation	1/46	R
FOREST	3rd level Forest or park	1/47-48	FO
DISTRT	4th level District	1/50-51	DI
HOUR	Time of failure	1/53-54	HR
MONTH	Month of failure	1/56-57	MO
YEAR	Year of failure	1/58-59	YR
STATE	State in which failure occurred	1/61-62	ST
COUNTY	County in which failure occurred	1/63-65	CO
SEASON	Whether in season for public use	1/67	S
OWNER	Land ownership	1/69	O
SITE	Site category	1/71	S
TARGET	Property or person affected	1/73	P
IFPROP	Property accident	(1/75) 2/7	D
LOSS	Dollar property loss	2/14-18	LOSS
INJURY	Number of injuries	(1/77) 2/20	I
MEDATT	Number requiring medical attention	2/22	M
FATAL	Number of fatalities	(1/79) 2/24	F
	Failure category—normal, catastrophe or urban	2/26	C
CDOLLAR	Value of property	2/27-31	CLAIM
SETTLE	Data field open for use	2/32	S
SDOLLAR	Total value including injuries, fatalities	2/33-38	SAMT
TREES	Uncoded failures associated with report + 1	2/40-42	NUM
CLEAN	Cleanup required	(1/80) 2/80	C

Examples of IF Statements

Some of the conventions used in IF statements are illustrated below. Only one of the IF statements shown here would normally be used in any one run of the PUNCH program. In these statements, .EQ. is "equal to," .NE. is "not equal to," .GT. is "greater than," .LT. is "less than," .GE. is "greater than or equal to," and .LE. is "less than or equal to." These examples illustrate both the inclusive GO TO PUNCH directive as well as the exclusive GO TO NOPUNCH when the directive is part of the IF statement. When GO TO NOPUNCH is used in the IF statement, all other than the designated items are selected. Multiple restrictions are illustrated in the last five statements. Note that nesting parentheses are used for clarity.

```
      IF (SPECIE .EQ. 001) GO TO PUNCH
GO TO NOPUNCH
```

Selects only data for species 001

```
      IF (SPECIE .NE. 001) GO TO NOPUNCH
```

Selects only data for species 001

```
      IF (SPECIE .GT. 002) GO TO NOPUNCH
```

Selects data for species 002 and below

```
      IF (SPECIE .LT. 003) GO TO PUNCH
GO TO NOPUNCH
```

Selects data for species 002 and below

```
      IF (SPECIE .GE. 003) GO TO NOPUNCH
```

Selects data for species 002 and below

```
      IF (SPECIE .LE. 002) GO TO PUNCH
GO TO NOPUNCH
```

Selects data for species 002 and below

```
      IF (AGENCY .EQ. 01 .AND. REGION .EQ. 5 .AND. FOREST .EQ. 02) GO
     $TO PUNCH
GO TO NOPUNCH
```

Selects data for forest, within region, within agency specified

```
      IF (SPECIE .LT. 800 .OR. SPECIE .GT. 826) GO TO NOPUNCH
```

Selects data for species 800 thru 826

```
      IF (SPECIE .EQ. 801 .AND. CLEAN .EQ. 9 .AND. CLAIM .EQ. 1) GO TO
     $PUNCH
GO TO NOPUNCH
```

Selects only California black oak catastrophe failures which did not cause accidents

```
      IF ((SPECIE .EQ. 801 .OR. SPECIE .EQ. 804) .AND. (YEAR .EQ. 40))
     $GO TO PUNCH
GO TO NOPUNCH
```

Selects data for species 801 and 804 failures which occurred in 1940

```
      IF ((DEFECT(1) .EQ. 01) .AND. (DEFECT(2) .EQ. 03 .OR. DEFECT(3)
     $.EQ. 03)) GO TO PUNCH
GO TO NOPUNCH
```

Selects only data for failures when trees were both dead and decayed

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USDA FOREST SERVICE
GENERAL TECHNICAL
REPORT PSW- 25 /1978

SIMULATING FOREST PICTURES BY IMPACT PRINTERS

Elliot L. Amidon E. Joyce Dye

In the applications of computers to forestry problems, the answers are usually shown in the form of text or tables. If a graphic presentation in hard copy form is needed, a problem arises if only a printer is available. This is particularly true at field locations. The occasional need for graphic output simply does not justify the maintenance of specialized equipment, such as incremental line plotters.

One solution to the hardware problem is to simulate pictures by producing shades of gray with the available printer. This solution is widely used to display remote sensing data. The problem becomes one of selecting the symbols to produce gray levels, from many possibilities. The approach is desirable for a quick look at large volumes of data. Pictorial quality is severely limited, however, since the space between symbols makes streaks in the density patterns.

Another alternative is to acquire a terminal that has both text and graphic capabilities. High-speed ink jet and electrostatic devices with this dual capability require substantial investments. They may be feasible at computer centers, but not field offices. A compromise is a mechanical printer/plotter that resembles a typewriter and costs about four times as much. Although slow, in plot mode it offers fine character positioning which allows removal of space between symbols, giving a smoother gradation of gray scales than a line printer can offer.

This report suggests procedures to generate images with either a line printer or a printer/plotter. It describes applications and offers examples based on the use of elevation data available for the contiguous United States. Methods are emphasized because character fonts are not standard, and some experimentation by the user should be expected.

Amidon, Elliot L., and E. Joyce Dye.
1978. **Simulating forest pictures by impact printers.** Gen. Tech. Rep. PSW-25, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Two mechanical devices that are mainly used to print computer output in text form can simulate pictures of terrain and forests. The line printer, which is available for batch processing at many computer installations, can approximate halftones by using overstruck characters to produce successively larger "dots." The printer/plotter, which is normally used as an interactive terminal, permits fine adjustment of the space between characters in the plot mode. This control over blank space improves tonal appearance and permits solid black. The two types of printers have complementary uses. The line printer is best for high volumes of data, while the slower printer/plotter offers a greater range of densities.

Oxford: 582–U681.3
Retrieval Terms: mapping systems; computer simulation; pattern recognition; impact printers; grey scale.

Generally the first output device acquired in a batch processing computer system is a line printer. Remote terminals are likely to be low-speed devices similar to a typewriter for hardcopy and perhaps a cathode-ray-tube (CRT), for transitory images. It was realized early that line printers could serve a dual purpose and produce gray-toned pictures by selecting appropriate symbols (Perry and Mendelsohn 1964).

Shaded graphics have diverse forestry applications. Research on pattern recognition by using data from satellites is aided by gray-toned pictures (Heller 1975). Digital terrain data collected by the military services cover the contiguous United States at a resolution of about one point per acre. Instead of contour lines, areas between contour lines can be shaded to indicate relief. A subjective form of relief representation is hill-shading—a laborious cartographic process that can be automated (Yoeli 1965). Recent analytical hill-shading models include subtle atmospheric effects in addition to just changing the sun angle (Brassel 1974). Some problems may require digitizing data from topographic maps or stereo models by using aerial photos. From these data the intervisibility between points can be computed under varied conditions and displayed as shaded patterns. (Travis and others 1975). Slopes or aspects can also be computed from terrain data and displayed by gray level classes (Sharpnack and Akin 1969).

Computer mapping systems based on the uniform grid determined by line printer conventions are widely available. Most systems were developed for urban applications, typically keying census data to alternate density levels forming a choropleth map. Perhaps the best known systems are SYMAP and GRID, developed by the Harvard Laboratory for Computer Graphics (Harvard University 1973). Newer grid systems allow a user to overlay land-use maps before displaying statistics as shades of gray (Federation of Rocky Mountain States 1977, Sinton 1976).

Numerous investigators have studied ways to improve the gray scale attainable with a line printer. Since the process is subjective, it is not surprising that they have reported dissimilar results, and that alternatives are available.

PICTURE SIMULATION WITH LINE PRINTER

The problem of producing a gray-tone image with a line printer involves a binary choice of resolution and many possible character combinations, called codes. A line has 10 characters per inch. Six lines per inch are considered normal and eight optional. If the input data are equally spaced row- and column-wise, then the output is distorted. If cells are interpolated into each line, the overall map dimensions are preserved, but there is local distortion. Data can be collected at intervals selected to fit the spacing of a particular line printer.

For a particular printer and character set, the objective will largely determine the number of codes used. If the purpose is quantitative such that a gray-tone code can be looked up in a legend regardless of its map position, then the limit is seven or eight (Dickinson 1973, p. 162). Although this number may be conservative, observation of numerous examples in the literature would suggest 10 as an upper limit. If the purpose is relief representation or simply pictorial, then the number of codes may be two or three times greater, or whatever number gives an impression of increasing density to the observer. The impression is only roughly related to the area of ink deposition because less quantifiable factors dominate.

Some considerations affecting ranking for a given font are (a) the number of overprints which affects both density and print time, (b) the effect of multiple ink layers in portions of the overprint, (c) the distribution of ribbon ink and character wear along the print line, and (d) the viewing conditions, particularly distance.

A major consideration is the formation of patches having directional or textural effects which are usually detrimental. Spurious textures are most likely to occur with the lightest shades, where there are few choices of symbols, and a smooth density transition is most difficult. One attempt to avoid distracting patterns led to a set of 37 symbols with up to six overstrikes (Henderson and Tanimoto 1974). Recognizable individual symbols may also distract the observer.

To represent relief, we decided to simulate a conventional graphic process called halftone printing. When enlarged tenfold, newspaper pictures are seen to be actually black dots or squares of different sizes. By constructing star-like dots of graduated sizes, we minimized spurious directional patterns. In halftone printing, neither completely white nor solid black areas occur. Text produced by a line printer also always has some blank space between characters, regardless of the number of overstrikes.

We constructed 16 graduated "dots" using up to eight overstrikes (*fig. 1*). Decreasing the number of

gray levels will raise contrast while increasing the likelihood of creating spurious plateaus or contours. A subset of 8 symbols ending with the penultimate level of the 16 will result in a maximum of 6 overstrikes (*fig. 2*). In addition to the advantage of reduced print time, a subset of eight symbols will be easier to form with diverse character fonts.

Elevation data for the Pyramid Peak quadrangle were assigned 16 gray level "dots," listed and reduced 6.6-fold (*fig. 7*). Another illustration produced using eight gray levels and the same reduction shows the change in contrast (*fig. 8*). Print times were essentially the same at 2 minutes.

Halftone dots are unsuitable for those applications, such as statistical output from computer mapping systems, in which the code must be distinguishable in a map legend as well as provide a separable shade of gray. We constructed two sets of eight codes which seem to us to meet the dual requirements. One set may prove more suitable than the other depending on the particular font available (*figs. 3, 4*). The two seem to give a greater range than a previously published set (Stucki 1969). Stucki's codes, like our two sets, uses a maximum of four overstrikes (*fig. 5*). All three sets were printed by using Pyramid Peak quadrangle data and reducing 6.6-fold (*figs. 9-11*). The subtle differences in appearance change with viewing distance. A spacing of six lines per inch was used. Experiments with eight lines per inch, an option not always available, showed no obvious gain in tonal effect.

PICTURE SIMULATION WITH PRINTER/PLOTTER

Both a line printer and a printer/plotter can mechanically produce text in an identical format of 10 characters per inch across a line and 6 or 8 lines per inch. Typically a printer/plotter is used as a remote terminal and prints characters individually at about 30 per second. The plotting capability is due to fine bidirectional increments. A solid, curved line can be produced, for example, by producing a string of overlapping periods.

Fine positional control enables the printer/plotter to remove the blank space between characters. This capability gives it three advantages over the line printer. First, the dark end of the gray scale is extended by diminishing or exactly removing the blank areas between symbols. Second, a greater diversity of codes is obtainable with a given number of overstrikes. Finally, flexibility is gained for computer mapping systems using a fixed grid. Both input and output grid cells may be square, thereby avoiding interpolation or distortion. Discrete-scale changes are also possible, with the exact multiple uniquely determined by the output device selected.

For example, our Diablo[1] daisy-wheel printer/plotter has an incremental movement resolution of 1/48th inch between lines and 1/60th inch between characters. With four line feeds and five horizontal spaces, a 1/12-inch square grid is attainable. The elevation data collected at 200-foot contour intervals were digitized from maps with a representative fraction of 1 to 250,000 at a map distance of 0.01 in. or 208.3 feet on the ground.[2] When these data are converted to gray level codes and printed at a 1/12-inch resolution, the scale of the shaded map is 1 to 30,000 or close to 2 inches per mile, which is a common scale used in forestry (California State Cooperative Soil-Vegetation Survey 1958).

The printer/plotter offers so many combinations of character symbols, positions, and spacings that grid cell size must be determined before selection begins. At a 1/12-inch resolution, there are 20 (4 X 5) print positions. A period could be printed at any one of the matrix positions, giving a very general capability of forming symbols. This choice is impractical because of time consumed and physical wear on the period. Instead, the darker areas can be formed more rapidly with larger symbols.

We decided upon 10 gray levels for relief representation. These levels can be illustrated in a legend (*fig. 6*). The northeast quarter of the Pyramid Peak quadrangle was printed and reduced 3.3-fold for comparison with the line printer images. Print time was 2 hours, 10 minutes or 31 sq. in. per hour (*fig. 12*). The cost in dollar terms is more elusive because the hardware configuration we used is not rented. The Pyramid Peak illustration cost about $7 to $8, assuming a 5-year depreciation period, maintenance, and one-shift use.

Some experimentation may be necessary to reproduce the appearance of the illustrations in this report.

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[1] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

[2] Elevation data are available from the National Cartographic Information Center, U.S. Geological Survey, 507 National Center, Reston, Virginia 22092.

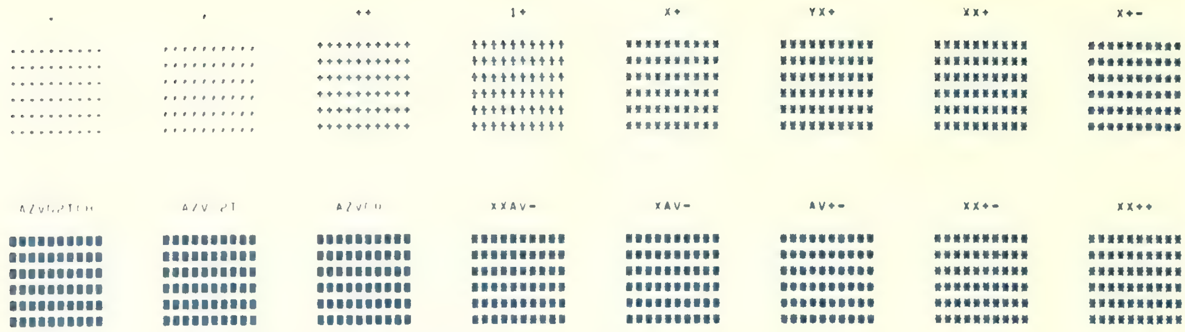

Figure 1—A set of 16 symbols for a halftone display, not including blank.

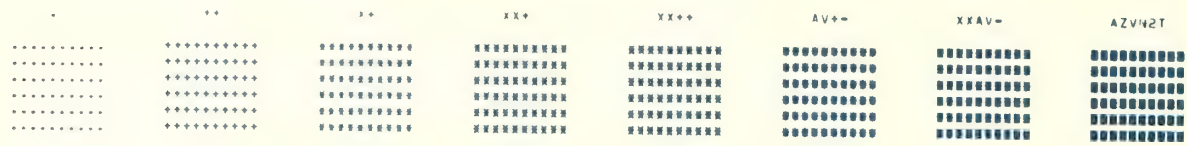

Figure 2—Eight halftone symbols from the above set of 16 (every odd-numbered symbol).

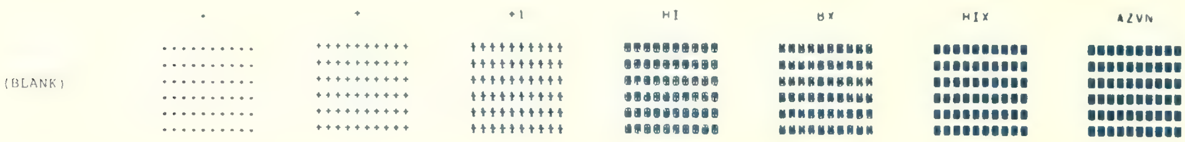

Figure 3—This set of eight gray tone symbols can be distinguished in a legend accompanying an illustration.

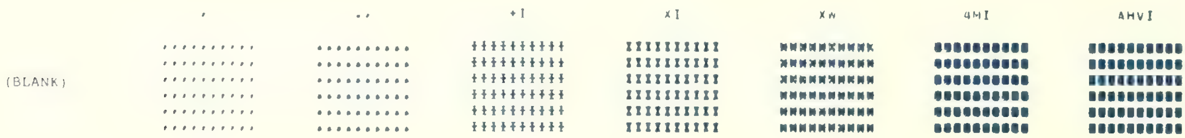

Figure 4—This set of eight separable gray codes may be more suitable with some line-printer character fonts.

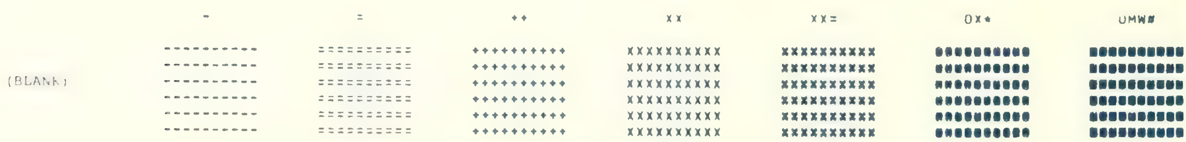

Figure 5—Stucki's set of eight gray level codes uses four overstrikes (Stucki 1969).

Figure 6—A printer/plotter set of 10 gray tones can be used in a map legend.

Figure 7—Digital elevation data spanning 4000 feet give an impression of relief when transformed into halftones.

Figure 8—Reducing the number of halftone "dots" from 16 to 8 increases contrast.

Figure 9—These terrain data were produced by the eight symbols of *figure 3.*

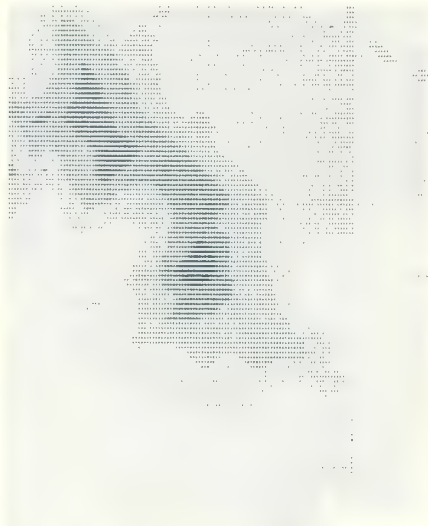

Figure 10—The same terrain illustrated in *figure 9* is pictured by using the eight symbols in *figure 4.*

Figure 11—The same Pyramid Peak data using Stucki's set of eight symbols (Stucki 1969).

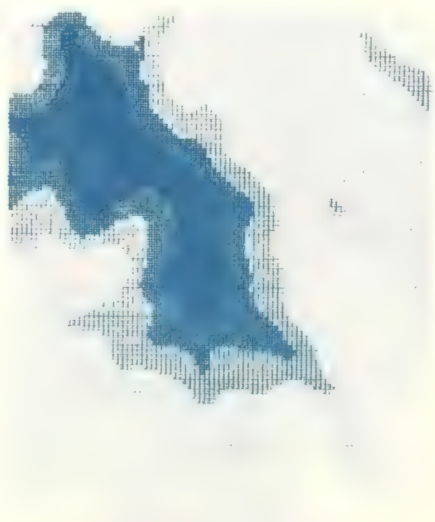

Figure 12—A printer/plotter representation of relief can be compared to the figures produced by line printer.

The character and overstrike patterns used to illustrate the terrain data (*figs. 7-12*) are shown in *figures 1-6:*

Symbols shown in these figures:	Were used to produce these figures:
1	7
2	8
3	9
4	10
5	11
6	12

In programming and operating a printer/plotter, we found several small ways to improve performance which may apply to like mechanical devices. We found the quality of an illustration to be strongly affected by the choice of ribbon. In most cases, film ribbon is preferable to cloth. Print time can be reduced about 5 percent just by printing in a zig-zag (boustrophedonic) fashion. In addition to the carriage return time saved, print quality is improved, which is attributed to reduced vibration. Print time can be reduced at the cost of additional programming. The data can be searched in advance of printing for blank lines or segments to skip over using the print suppression and tabbing features available.

Two versions of a sample subroutine (PATT) for reading and processing data into a gray-scale representation are reproduced in the *Appendix.* These listings will reduce development time by prospective users. Subroutine PATT can be called by a simple FORTRAN main program. PATT reads unblocked records from tape but other formats and storage media can be used with slight program modifications.

The first version was developed on a NOVA 2 with a DTC printer/plotter. The corresponding UNIVAC version includes horizontal expansion of the data to compensate for line printer distortion. The eight print symbols for the line printer are those of *fig. 3,* but other sets may be substituted readily.

CONCLUSIONS

The two types of printers are not alternatives since they differ greatly in output speed. They can complement each other. The line printer provides a "quick-look" at, say, a large volume of remote sensing printout. The precise positioning ability of the printer/plotter is best used for presentation where appearance is more important. Line printers are widely available and standardized in many respects. Some modification of character sets may still be required because of differences in fonts, inking methods, and wear. The gray-level symbols that we have provided should save time in finding the best set for simulating pictures on other printers.

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Subroutine PATT–Version for NOVA 2/DTC 1200 printer/plotter

```
      PARAMETER NOG=10
      SUBROUTINE PATT(BUF,LEL,IEL,IC,JC,IR,JR,NCOL)
C PRINTS SQUARE BLOCKS, 1/12 INCH X 1/12 INCH, ON THE DTC 1200.
C ASSEMBLY LANGUAGE ROUTINE 'OUTC' FEEDS EACH CHARACTER
C       TO THE PRINT BUFFER.
C EACH BLOCK CONTAINS 5 HORIZONTAL AND 4 VERTICAL PRINT POSITIONS.
C THERE ARE 13 PATTERNS OF 5 CHARACTERS EACH.  EACH  BLOCK IS MADE
C       UP OF 4 OF THESE PATTERNS.  THERE ARE 10 POSSIBLE SETS OF
C       PATTERNS TO PRINT BLOCKS GIVING 10 GREY SCALES.
C BUF IS THE ARRAY TO RECEIVE DATA FROM INPUT FILE.
C LEL IS THE LOWEST VALUE IN THE DATA.
C IEL IS THE HIGHEST VALUE IN THE DATA.
C IC IS THE BEGINNING POSITION TO BE PRINTED FROM EACH DATA
C       RECORD, JC IS THE ENDING POSITION.
C IR IS THE FIRST DATA RECORD TO BE USED, JR IS THE LAST.
C NCOL IS THE TOTAL NUMBER OF WORDS IN EACH INPUT RECORD.
      COMMON/A/IPAT(5,13),ISQ(4,NOG),INH80(3),ISP(2)
      INTEGER LINE(1450),BUF(NCOL)
      DATA IPAT/40K,40K,40K,40K,40K,   40K,40K,47K,40K,40K,
     : 40K,40K,54K,40K,40K,  40K,40K,40K,54K,40K,  40K,40K,40K,73K,40K,
     : 40K,56K,40K,40K,40K, 40K,72K,40K,40K,40K, 111K,40K,53K,40K,111K,
     : 111K,53K,111K,53K,111K, 72K,72K,72K,72K,72K, 73K,73K,73K,73K,73K,
     :  40K,53K,40K,53K,40K,   111K,111K,111K,111K,111K/
      DATA ISQ/1,1,1,1,  1,1,1,2,  3,1,1,1,  4,6,1,1,  5,6,1,1,
     :  5,7,1,1,   1,1,8,1,   1,1,9,1,  1,12,13,12,   1,10,11,1/
      DATA INH80/-1,2,40000K/
      DATA ISP/40K,10K/
C IZIG CONTROLS DIRECTION OF PRINTING, TO AVOID UNNECESSARY
C       CARRIAGE RETURNS.
      IZIG=1
      INVL=(IEL-LEL)/NOG
C OPEN PRINT FILE.
      CALL OPEN(10,'$TTO',INH80,IER10)
      IF(IER10.NE.1) GO TO 90
C OPEN DATA FILE.
      CALL OPEN(2,'EVEL',0,IER2,175)
      IF(IER2.NE.1) GO TO 90
C PUT PRINT FILE IN PLOT MODE.
      TYPE "<6>"
C OUTER LOOP FOR PRINTING STRIPS.
      DO 39 MA=IC,JC,145
      WRITE(10,1000)
      MB=MIN0(MA+144,JC)
C LTOT=TOTAL CHARACTER POSITIONS PER LINE.
      LTOT=(MB-MA+1)*5
C IF IR IS NOT FIRST RECORD, SKIP RECORDS 1 THROUGH KR.
      IF(IR.EQ.1) GO TO 23
      KR=IR-1
      DO 24 J=1,KR
      READ (2,2000,END=90,ERR=90)(BUF(I),I=1,NCOL)
   24 CONTINUE
C PROCESS RECORDS.
   23 DO 80 IREC=IR,JR
```

```
      READ(2,2ØØØ,ERR=9Ø,END=9Ø)(BUF(I),I=1,NCOL)
 2ØØØ FORMAT(1X,25I4)
C FIND PATTERN SET FOR EACH DATA VALUE.
      DO 26 I=MA,MB
   26 BUF(I)=MINØ(((BUF(I)-LEL)/INVL)+1,NOG)
C STORE AND PRINT CHARACTERS AND SPACING FOR EACH LINE.
      DO 6Ø IR=1,4
      IL=Ø
      DO 5Ø IH=MA,MB
      M=BUF(IH)
      IF(M.GT.NOG) GO TO 91
      IF(M.LT.1) GO TO 91
      K=ISQ(IR,M)
      DO 4Ø L=1,5
      IL=IL+1
      IF(IL.GT.145Ø) GO TO 91
      LINE(IL)=(IPAT(L,K))
      IF(LINE(IL).EQ.ISP(1)) GO TO 38
      IL=IL+1
      IF(IL.GT.145Ø) GO TO 91
   38 LINE(IL)=ISP(IZIG)
   4Ø CONTINUE
   5Ø CONTINUE
C SKIP DIRECTLY TO LINE FEED IF LINE IS ALL BLANKS.
      IF(IL.EQ.LTOT) GO TO 6Ø
      IF(IZIG.EQ.2) GO TO 56
      DO 55 L=1,IL
   55 CALL OUTC(LINE(L))
      GO TO 58
   56 DO 57 I=1,IL
   57 CALL OUTC(LINE(IL-I+1))
   58 IZIG=3-IZIG
   6Ø CALL OUTC(12K)
   8Ø CONTINUE
      REWIND 2
   89 CONTINUE
C LEAVE PLOT MODE.
      TYPE "<33><6>"
      WRITE(1Ø,1ØØØ)
 1ØØØ FORMAT(1H1)
      RETURN
C ERROR MESSAGES.
   9Ø TYPE "<33><6>"
      WRITE(1Ø,9ØØØ),IER1Ø,IER2,IREC
 9ØØØ FORMAT('ØFILE ERROR, IER1Ø=',I4,6X,'IER2=',I4,6X,'IREC=',I4)
      RETURN
   91 TYPE"<33><6>"
      WRITE(1Ø,9ØØ1),MA,MB,IH,M,IL
 9ØØ1 FORMAT('ØBAD SUBSCRIPT FOR ISQ OR LINE: MA,MB,IH,M,IL=',5I8)
      RETURN
      END
*>
```

Subroutine PATT—Version to run on UNIVAC 1108 (Exec. 8) with standard line printer

```
C OVERPRINTS ZERO TO FOUR CHARACTERS TO GIVE EIGHT GREY SCALES, USING A
C        UNIVAC 1108 WITH STANDARD LINE PRINTER OF 10 CHARACTERS/INCH AND
C        6 LINES/INCH.  TO CORRECT FOR OVERALL DISTORTION, FOUR OUT OF
C        EACH SIX HORIZONTAL CHARACTERS ARE PRINTED TWICE.
C KUF IS THE ARRAY TO RECEIVE DATA FROM INPUT FILE.
C LEL IS THE LOWEST VALUE IN THE DATA.
C IEL IS THE HIGHEST VALUE IN THE DATA.
C IC IS THE FIRST POSITION TO BE PROCESSED FROM EACH DATA RECORD,
C        JC IS THE LAST.
C IR IS THE FIRST DATA RECORD TO BE USED, JR IS THE LAST.
C NCOL IS THE TOTAL NUMBER OF WORDS IN EACH INPUT DATA RECORD.
      PARAMETER NOG=8, NL=130
      INTEGER BUF(NL),KUF(NCOL)
      INTEGER LINE(NL)
      INTEGER CHARS(4,NOG)
C OUR 8, SET 1.
      DATA (CHARS(1,I),I=1,NOG)/1H ,1H.,1H+,1H+,1HH,1HB,1HH,1HA/
      DATA (CHARS(2,I),I=1,NOG)/1H ,1H ,1H ,1H1,1HI,1HX,1HI,1HZ/
      DATA (CHARS(3,I),I=1,NOG)/1H ,1H ,1H ,1H ,1H ,1H ,1HX,1HV/
      DATA (CHARS(4,I),I=1,NOG)/1H ,1H ,1H ,1H ,1H ,1H ,1H ,1HN/
      INVL=(IEL-LEL)/NOG
C NC IS THE MAXIMUM NUMBER OF HORIZONTAL CHARACTERS THAT CAN BE EXPANDED
C        BY 4/6 AND FIT IN A PRINT LINE OF 130 SPACES.
      NC=(6*NL)/10
C OUTER LOOP FOR PROCESSING STRIPS.
      DO 89 MA=IC,JC,NC
      MB=MIN(MA+NC-1,JC)
      PRINT 1000
 1000 FORMAT(1H1)
C IF IR IS NOT THE FIRST RECORD, SKIP RECORDS 1 THROUGH IR-1.
      IF(IR.EQ.1) GO TO 5
      KR=IR-1
      DO 4 IREC=1,KR
      CALL NTRAN(10,2,NCOL,KUF,L)
      CALL NTRAN(10,22)
    4 CONTINUE
C PROCESS RECORDS.
    5 DO 80 IREC=IR,JR
      CALL NTRAN(10,2,NCOL,KUF,L)
      CALL NTRAN(10,22)
      IF(L.NE.NCOL) GO TO 800
C EXPAND EACH 6 VALUES TO 10.
      W=.05
      L=0
```

Subroutine PATT–Version to run on UNIVAC 1108 (Exec. 8) with standard line printer (continued)

```
      K=0
      DO 10  J=MA,MB
      K=K+1
   10 KUF(K)=((KUF(J)-LEL)/INVL)+1
      DO 15 J=1,K
      D=J
      D=D/6.
   13 IF(W.GT.D) GO TO 15
      L=L+1
      W=W+.1
      BUF(L)=MIN(KUF(J),NOG)
      GO TO 13
   15 CONTINUE
C NR INDICATES MAXIMUM NUMBER OF OVERSTRIKES FOR ALL CHARACTERS IN
C        PRINT LINE.
      NR=1
      DO 52 K=1,L
      NF=BUF(K)
      NR=MAX(NR,NF)
   52 LINE( K)=CHARS(1,NF)
      NR=NR/2
C SKIP TO NEXT RECORD IF THIS ONE  WOULD BE ALL BLANKS.
      IF(NR.LT.1) GO TO 80
      PRINT 1001,(LINE(J),J=1,L)
 1001 FORMAT(1H ,130A1)
      IF(NR.LT.2) GO TO 80
C PRINT OVERSTRIKES.
      DO 54 ICR=2,NR
      DO 53 K=1,L
      NF=BUF(K)
   53 LINE( K)=CHARS(ICR,NF)
      PRINT 1002,(LINE(J),J=1,L)
 1002 FORMAT(1H+,130A1)
   54 CONTINUE
   80 CONTINUE
      CALL NTRAN(10,10)
      CALL NTRAN(10,22)
   89 CONTINUE
      GO TO 900
  800 PRINT 8000,L,IR
 8000 FORMAT('0READ ERROR=',I3,' AT ROW',I4)
  900 RETURN
      END
```

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